SN-230

TRANSPIRATION AND FILM COOLING BOUNDARY LAYER COMPUTER PROGRAM

VOLUME II

Computer Program and User's Manual

FINAL REPORT-CONTRACT NAS7-791

JUNE 1971

PREPARED BY: ROGER J. GLOSS

PREPARED FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

DYNAMIC SCIENCE
A Division of Marshall Industries
2400 Michelson Drive, Irvine, California 92664 (714) 833-2670

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FOREWORD

The present report is part of a two volume set which describes a turbulent boundary layer analysis and computer program that includes the effects of wall cooling and equilibrium chemistry. Volume I contains the analytical basis for the computer program and a discussion of the results obtained to date: Volume II of the set describes the computer program and serves as a user's manual.

This investigation is entitled TRANSPIRATION AND FILM COOLING BOUNDARY LAYER COMPUTER PROGRAM. The two volumes are additionally subtitled as follows:

Volume I - Numerical Solution of the Turbulent Boundary Layer Equations With Equilibrium Chemistry - by Jay N. Levine

Volume II - Computer Program and User's Manual - by Roger J. Gloss

Volumes I and II, and the computer program, have been distributed according to the attached distribution lists. Additional copies of the two volumes and the computer program (UNIVAC 1108 and IBM 360 versions) may be obtained from T. Reedy, CPIA, APL/JHU, 8621 Georgia Avenue, Silver Spring, Maryland 20910.

This investigation was conducted for the Jet Propulsion Laboratory, National Aeronautics and Space Administration under contract No. NAS7-791 with Walter B. Powell as technical monitor. Jay N. Levine of Dynamic Science was Program Manager.

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NOMENCLATURE

A	-	Van Driest damping constant in eddy viscosity formula
A_n, B_n, C_n	-	coefficients in the difference equations
b	-	value of $\tilde{y}_e$ at the initial station
C_p	-	specific heat
c_i	-	mass fraction of the ith species
C_f	-	local shear stress coefficient
D_n	-	right hand side of difference equations
D_T	-	eddy diffusivity
E	-	$\rho G' \zeta' \tilde{y} / \zeta$
F	-	$G' / \zeta^2 \, Re_r$, also thrust
G	-	function used to transform $\tilde{y}$
G', G''	-	1st and 2nd derivatives of the G function
H	-	total enthalpy, also shape factor = δ^* / θ
h	-	static enthalpy
j	-	equals 1 for axisymmetric flow, 0 for planar flow
K	-	acceleration parameter
k	-	thermal conductivity, also common ratio in geometric stepsize progressions
L	-	reference length
Le	-	molecular Lewis number
Le_T	-	turbulent Lewis number
ℓ	-	mixing length
M	-	molecular weight
$\dot{m}_w$	-	surface mass transfer rate = $\rho_w v_w$
m,n	-	mesh indicies
n	-	parameter in G function
P	-	pressure
P_{amb}	-	ambient pressure at nozzle exit
Pr	-	Prandtl number
Pr_T	-	turbulent Prandtl number
q_w	-	local heat transfer rate
r^*	-	nozzle throat radius
r_w	-	local radius of the wall

R	-	Universal gas constant
Re	-	Reynolds number
S	-	entropy
s	-	wetted length along wall
St.	-	Stanton number
T	-	temperature
u,v	-	velocity in s and y directions, respectively
u^+	-	dimensionless velocity ratio, $\bar{u}/u_w^*$
u_w^*	-	friction velocity, $(\tau_w/\bar{\rho}_w)^{1/2}$
v	-	velocity in y direction
v_w^+	-	dimensionless velocity ratio, $\bar{v}_w/u_w^*$
x	-	axial distance
y	-	normal coordinate
y^+	-	dimensionless normal coordinate, $\bar{y}\, u_w^*/\bar{\nu}$
$\tilde{y}$	-	nondimensional y coordinate = $\bar{y}/L\zeta$
α	-	constant in G function
α_i	-	mass fraction of the ith element
$\alpha_{i_{trans}}$	-	mass fraction of the ith element in the transpiration coolant
β	-	constant in G function
γ	-	ratio of specific heats
δ	-	boundary layer thickness
δ^*	-	displacement thickness
δ^*_{inc}	-	incompressible displacement thickness
ϵ	-	kinetmatic eddy viscosity
ζ	-	function used to scale $\bar{y}$
ζ'	-	$d\zeta/ds$
θ	-	momentum thickness
$\varkappa$	-	eddy conductivity

μ	-	molecular viscosity
ν	-	kinematic viscosity
ρ	-	density
$\sigma_1 \cdots \sigma_5$	-	used to represent various transport property terms
τ	-	shear stress

Subscripts

e	-	at the edge of the boundary layer
i	-	pertaining to the ith species
r	-	evaluated at reference conditions
w	-	at the wall
y	-	partial derivative with respect to y
yy	-	2nd partial derivative with respect to y

Superscripts

j	-	equals 1 for axisymmetric flow, 0 for two dimensional flow
'	-	denotes a fluctuating term
-	-	denotes a dimensional variable and/or a time averaged quantity

1. INTRODUCTION

This report describes a new finite difference turbulent boundary layer computer program which allows for mass transfer wall cooling and equilibrium chemistry effects. Volume I of this set describes the analytical foundation of the program and contains a discussion of many of the solutions achieved to date.

The program is capable of calculating laminar or turbulent boundary layer solutions for an arbitrary ideal gas or an equilibrium hydrogen oxygen system. Either two dimensional or axisymmetric geometric configurations may be considered.

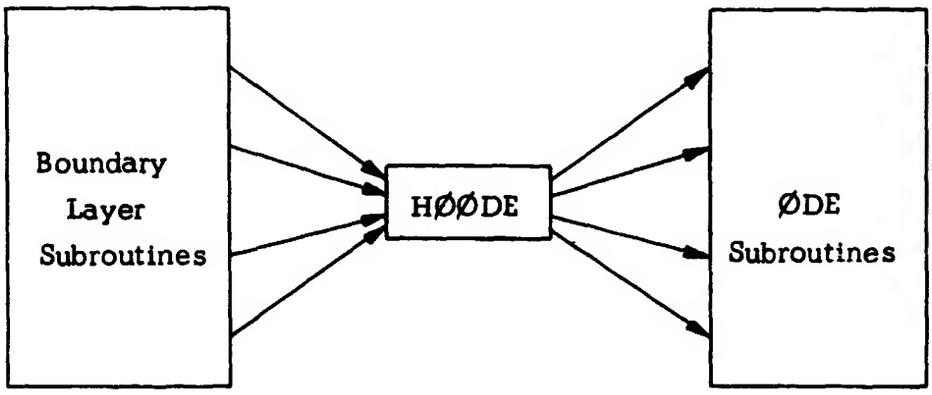
The equations are solved, in nondimensionalized physical coordinates, using the implicit Crank-Nicolson technique. The finite difference forms of the conservation of mass, momentum, total enthalpy and elements equations are linearized and uncoupled, thereby generating easily solvable tridiagonal sets of algebraic equations.

The computer program is written in A.S.A. standard FORTRAN IV, and versions are now operational on UNIVAC 1108 and IBM 360 computers.

This volume is designed to serve as a detailed description of the computer program, as well as a program user's manual. Detailed descriptions of all boundary layer subroutines are included, as well as a section defining all program symbols of principal importance. Instructions are then given for preparing card input to the program and for interpreting the printed output. Finally, two sample cases are included to illustrate the use of the program.

2. PROGRAM DESCRIPTION

The Mass Addition Boundary Layer Program is actually composed of two distinct modules or collections of subroutines: (1) a boundary layer analysis which contains all subroutines necessary for a perfect gas case, and (2) the One Dimensional Equilibrium Program (ØDE), modified to operate in a subroutine mode and to solve, in particular, the hydrogen-oxygen chemical system. These two modules interface, in a hydrogen-oxygen equilibrium case, via a single subroutine HØØDE.



In this section, all program subroutines are described briefly. Detailed documentation then follows for all boundary layer subroutines and for subroutine HOODE. Although the equilibrium subroutines are not discussed in detail, subroutines CPHS, EQLBRM, MATRIX, MGAUSD, REACT, and SEARCH are described in the Two Dimensional Kinetic Reference Program (TDK) document (Reference 1).

Boundary Layer Subroutines

AD' PT - Adds mesh point at edge of boundary layer.

BN CND - Calculates wall and edge conditions at forward station.

CØNTNU - Integrates continuity equation to obtain ρv.

DEBUG - Error subroutine which indicates origin of program-detected error.

DUMPIT - Dumps matrix coefficients of a given difference equation at selected stations.

EDDY - Calculates turbulent transport properties ϵ, Pr_T, Le_T.

ELEMTS - Solves element conservation equation for mass fraction of hydrogen α.

ENERGY - Solves energy equation for enthalpies H and h.

EXECUT - Execution control subroutine.

GFUNC - Generates boundary layer stretching function G and calculates boundary layer mesh.

HØØDE - Interface subroutine which calls One Dimensional Equilibrium subroutines to calculate equilibrium properties for hydrogen-oxygen system.

IGØDE - Calculates thermodynamic and laminar transport properties for perfect gas case.

ITERAT - Updates average properties and calculates auxiliary quantities for a given iteration on boundary layer equations.

LCURV - Linear interpolation subroutine.

MØMNTM - Solves momentum equation for velocity u.

NLØUT - Prints out program input.

PARAMS - Calculates gross boundary layer parameters at a given station.

PHØENX - Interpolates for missing values in a table in which every nth value is known.

PRINT - Stores items in summary table at each station and prints profiles at a given station if requested.

PRØFIL - Generates initial dependent variable profiles across boundary layer at start of case.

RDTAPE - Reads restart data from tape for a restart case.

STEP - Determines stepsize and calculates contour properties at forward station.

SUMTAB - Writes summary table at end of case.

TABLES - Normalizes input tables and initializes wall and edge conditions.

TFCBL - Main program which reads input data and controls calculations at initial station.

TRIM- Solves system of linear equations whose matrix of coefficients is tridiagonal.

XNTERP - Averaged parabolic interpolation subroutine.

ZFUNC - Evaluates boundary layer normalization function ζ every iteration.

One-Dimensional Equilibrium Subroutines

ANSWER - Calculates total number of moles, sound speed, and density based on equilibrium solution.

BLØCK DATA - Stores atomic symbols, weights and valences.

CPHS - Calculates species enthalpies and total specific heat from temperature curve fits.

CPSPEC - Calculates specific heat for each species from temperature curve fits.

EQLBRM - Calculates equilibrium composition and properties.

HPCALC - Performs a series of up to thirteen enthalpy-pressure equilibrium calculations.

MATRIX - Constructs the iteration equations required for the equilibrium solution.

MGAUSD - Solves linear set of up to twenty simultaneous equations using modified Gaussian elimination.

ØDE - Initialization subroutine for equilibrium portion of program.

REACT - Reads and processes REACTANTS data.

SEARCH - Reads, processes, and stores THERMØ data.

SPCALC - Performs a series of up to thirteen entropy-pressure equilibrium calculations.

TPCALC - Performs a single temperature-pressure equilibrium calculation.

VISCX - Calculates viscosity and Prandtl number for hydrogen-oxygen system using mixture formulas.

SUBROUTINE ADDPT

This subroutine adds another mesh point at the edge of the boundary layer and prepares for recalculation of the difference equation coefficients for the last two equations in the matrix solution. ADDPT may be called from the following subroutines under the conditions specified:

(1) from MØMNTM, if, after solving the momentum equation,

$$\frac{1}{u_e}\left|\left(\frac{du}{dy}\right)_e\right| > \text{EPSLN1 (input)};$$

(2) from ENERGY, if, after solving the energy equation,

$$\frac{1}{H_e}\left|\left(\frac{dH}{dy}\right)_e\right| > \text{EPSLN2 (input)};$$

(3) from ELEMTS, if, after solving the element conservation equation,

$$\frac{1}{\alpha_e}\left|\left(\frac{d\alpha}{dy}\right)_e\right| > \text{EPSLN3 (input)}.$$

Subroutine ADDPT is called as follows:

CALL ADDPT (IFLAG)

where

IFLAG is a flag (integer) indicating the subroutine from which ADDPT is called:

- = 1, if ADDPT is called from subroutine MØMNTM (i.e. the momentum equation does not satisfy the edge criterion);
- = 2, if ADDPT is called from subroutine ENERGY (i.e. the energy equation does not satisfy the edge criterion);
- = 3, if ADDPT is called from subroutine ELEMTS (i.e. the element equation does not satisfy the edge criterion).

Subroutine ADDPT first increments NY, the number of points in the boundary layer by one. Accordingly,

$$NY = NY + 1$$
$$NY1 = NY - 1$$
$$NY2 = NY - 2$$

During initialization, the arrays for y, $\tilde{y}$, G', and G'', were already evaluated for the maximum possible number of points in the boundary layer, so that these quantities are already stored for the newly added point. All other properties which vary across the boundary layer, however, must be extended to the new point. For all properties except those noted here, this amounts to setting the value at the new point equal to the value at the old edge point. For example, for velocity,

$$U(NY, J) = U(NY1, J) \quad \text{for } J = 1,2,3.$$

Note that NY1 is the subscript for the point which was previously the edge of the boundary layer but is now the first interior point. Note also that back, average, and forward values are extended.

The quantity RHØV (ρv) is not constant at the edge but is integrated to obtain the value at the new point:

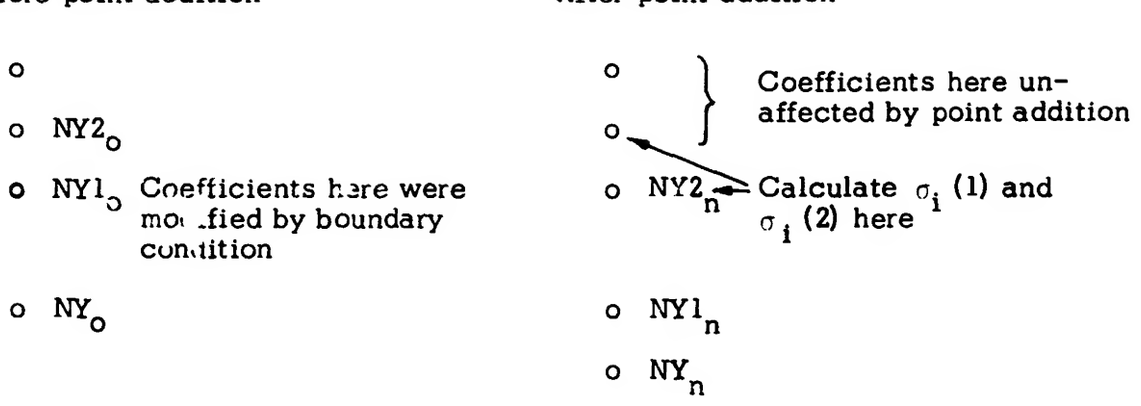
$$\rho v_{NY} = \rho v_{NY1} + \Delta y \left.\frac{d(\rho v)}{dy}\right|_{NY1}$$

where $\left.\frac{\partial(\rho v)}{dy}\right|_{NY1}$ is parabolic derivative at the old edge point.

The auxiliary quantities E and F are then evaluated at the new point NY.

Following return from subroutine ADDPT, the equation which necessitated the addition of the point will be solved again and the solution will be checked to see if it satisfies the edge criterion. Before doing this, however, the difference equation coefficients for the points near the edge must be recalculated due to changes resulting from addition of the new point. The following discussion refers

to the diagram below.



After point addition, all coefficients for points interior to $NY2_n$ are unchanged and need not be recalculated. At $NY2_n$ the coefficients were modified to account for the boundary condition at NY_o, but $NY2_n$ is now merely an interior point whose coefficients depend on other interior points. Thus the coefficients must be recalculated at $NY2_n$ by the calling routine, and to do this, the σ_i (1) and σ_i (2) must be calculated in ADDPT at $NY2_n - 1$ and $NY2_n$ respectively. Accordingly, if IFLAG = 1, ADDPT calculates σ_1 at these points for the momentum equation; if IFLAG = 2, ADDPT calculates σ_2, σ_3, and σ_4 for the energy equation; if IFLAG = 3, ADDPT calculates σ_5 for the element equation.

Finally, before returning to the calling routine, subroutine ADDPT prints the following message:

POINT WAS ADDED TO BOUNDARY LAYER IN SUBROUTINE {MOMNTM / ENERGY / ELEMTS} AT STATION _____ AND ITERATION _____.

SUBROUTINE BNDCND

This subroutine obtains values at the forward station (m+1) of quantities necessary for the difference equation boundary conditions. Previous forward values of $\frac{dP_e}{ds}$, $\frac{du_e}{ds}$, and $\dot{m}_w$, are first stored as the back values for the new station. The following quantities are then obtained:

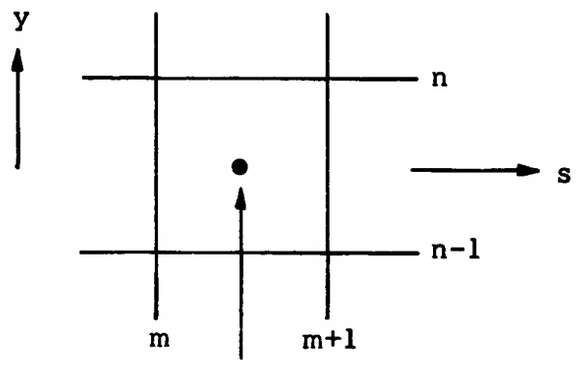
Name	Quantity	How Obtained
DUEDSN	$\left.\frac{du_e}{ds}\right\|_{m+1}$	$\left.\frac{du_e}{ds}\right\|_{m+1} = \left.\frac{du_e}{dx}\right\|_{m+1} \cos\theta_{w_{m+1}}$, where $\left.\frac{du_e}{dx}\right\|_{m+1}$ is obtained by interpolation using LCURV.
DUEDS	$\frac{du_e}{ds}$	Average of m and m+1.
UEDGE	$u_{e_{m+1}}$	Euler integration: $u_{e_{m+1}} = u_{e_m} + \Delta s \frac{du_e}{ds}$,
SMDWN	$\dot{m}_{w_{m+1}}$	$\dot{m}_{w_{m+1}} = \frac{\bar{\dot{m}}_{w_{m+1}}}{\rho_r u_r \zeta_{m+1}}$, where $\bar{\dot{m}}_{w_{m+1}}$ is obtained by linear interpolation using LCURV.
SMDW	$\dot{m}_w$	Average of m and m+1.
TWALL	T_w	Linear interpolation using LCURV.
PEDGEB	$\bar{P}_e$	Interpolation using XNTERP.
DPEDSN	$\left.\frac{dP_e}{ds}\right\|_{m+1}$	$\left.\frac{dP_e}{ds}\right\|_{m+1} = \frac{1}{\rho_r u_r^2} \left.\frac{d\bar{P}_e}{dx}\right\|_{m+1} \cos\theta_{w_{m+1}}$ where $\left.\frac{d\bar{P}_e}{dx}\right\|_{m+1}$ is obtained using XNTERP.
DPEDS	$\frac{dP_e}{ds}$	Average of m and m+1.

SHEDGE	h_e	$h_e = H_e - u_e^2/2$, where H_e was calculated initially and is constant.
SHWALL	h_w	For an equilibrium case, subroutine HØØDE is called to obtain h_w from a temperature-pressure calculation using T_w and P_e. For a perfect gas case, subroutine IGØDE is called with T_w and P_e to obtain h_w. Then $h_w = \frac{h_w}{u_r^2}$. In both cases $H_w = h_w$.
HWALL	H_w	

SUBROUTINE CØNTNU

Subroutine CØNTNU integrates the continuity equation to determine ρv vs y at each mesh point across the boundary layer.

The continuity equation is solved at m + 1/2, that is, at a distance halfway between the back station m and the forward station m + 1. The derivatives and coefficients are evaluated at m + 1/2, n - 1/2. (See diagram.)



m+1/2, n-1/2

Thus, for example,

$$r_{w_{m+1/2}} = \frac{1}{2}\left(r_{w_m} + r_{w_{m+1}}\right)$$

$$\tilde{y}_{n-1/2} = \frac{1}{2}\left(\tilde{y}_n + \tilde{y}_{n-1}\right)$$

We also have

$$\rho u_{m+1/2,\ n-1/2} = \frac{1}{4}\left(\rho u_{m,n} + \rho u_{m,n-1} + \rho u_{m+1,n} + \rho u_{m+1,\ n-1}\right)$$

$$\frac{\partial \rho u}{\partial s} = \frac{1}{2\Delta s}\left(\rho u_{m+1,n} + \rho u_{m+1,\ n-1} - \rho u_{m,n} - \rho u_{m,n-1}\right)$$

$$\frac{\partial \rho u}{\partial y} = \frac{1}{2\Delta y}\left(\rho u_{m+1,n} + \rho u_{m,n} - \rho u_{m+1,\ n-1} - \rho u_{m,n-1}\right)$$

$$\frac{\partial \rho v}{\partial y} = \frac{1}{\Delta y}\left(\rho v_{m+1/2,n} - \rho v_{m+1/2,\ n-1}\right)$$

With the properties and derivatives established in this manner, the continuity equation is integrated as follows:

$$\rho v_{m+1/2,1} = \dot{m}_{w_{m+1/2}} \quad \text{at the wall;}$$

$$\rho v_{m+1/2,n} = \rho v_{m+1/2,n-1} + \left\{ -\frac{1}{G'_{n-1/2}} \frac{\partial \rho u}{\partial s} - \frac{\rho u_{m+1/2,n-1/2}}{G'_{n-1/2}\, r_{w_{m+1/2}}} \left. \frac{dr_w}{ds} \right|_{m+1/2} + \left(\frac{\zeta'}{\zeta} \tilde{y} \right)_{m+1/2,n-1/2} \frac{\partial \rho u}{\partial y} \right\} \Delta y$$

SUBROUTINE DEBUG

This subroutine is called when the program detects an error; it prints a message indicating where and when the error occurred, causes the summary table up to this point to be printed, and then terminates program execution by calling EXIT. Subroutine DEBUG is called as follows:

CALL DEBUG (SNAME)

where SNAME is a single cell containing the Hollerith representation of the name of the calling routine, where the error was encountered.

Subroutine DEBUG prints the following message:

EXIT CALLED FROM SUBROUTINE [SNAME] AT STATION _____
AND ITERATION _____.

Subroutine DEBUG then calls subroutine SUMTAB to print the summary table (See description of subroutine SUMTAB.) and finally calls EXIT.

SUBROUTINE DUMPIT

This subroutine optionally prints program debugging information over a specified range of stations for a given case. Either the momentum equation or the energy equation matrix coefficients, as well as the values u, H, h, and ρv are printed for the first five and last five mesh points in the boundary layer. The output numbers are not labelled; however, they may be identified by comparison with the WRITE statements in subroutine DUMPIT which produce them.

See the section on Additional Program Features for instructions for implementing this debug capability.

SUBROUTINE EDDY

This subroutine is called every iteration to calculate the eddy viscosity ϵ, turbulent Prandtl number Pr_T, and turbulent Lewis number Le_T at each mesh point, based on the latest iteration values of all the other boundary layer properties.

The eddy viscosity calculation begins at the wall point and proceeds toward the edge. A quantity ϵ_i and a quantity ϵ_o are calculated at each mesh point, and $\epsilon = \epsilon_i$ at each point until $\epsilon_i \geq \epsilon_o$ for some point. From that point on out to the edge of the boundary layer, only ϵ_o is calculated, and $\epsilon = \epsilon_o$.

The equation for ϵ_i is

$$\epsilon_i = K_1^2 \, Re_r \, \zeta \, G' \tilde{y}^2 \left| \frac{\partial u}{\partial y} \right| (1-e^{\alpha})^2 ,$$

where

$$K_1 = 0.4,$$

$$\alpha = - \frac{Re_r \, \zeta \tilde{y} \, N}{26 \mu} \left(\frac{\rho \mu_w G'_w}{Re_r \, \zeta} \left. \frac{\partial u}{\partial y} \right|_w \right)^{1/2} .$$

In the expression for α, N is calculated in one of two ways. If $m_w \neq 0$,

$$N = \left\{ - \frac{\partial P_e}{\partial s} \frac{\mu}{\mu_w G'_w \left. \frac{\partial u}{\partial y} \right|_w \dot{m}_w} (1 - e^{\beta}) + e^{\beta} \right\}^{1/2}$$

where

$$\beta = \frac{11.8 \, \dot{m}_w}{\mu \rho_w^{1/2}} \left[\frac{Re_r \, \zeta^3 \, \mu_w}{G'_w \left. \frac{\partial u}{\partial y} \right|_w} \right]^{1/2} .$$

If $\dot{m}_w = 0$, then N is constant across the boundary layer, and

$$N = \left\{ 1 + \frac{11.8}{\rho_w^{1/2}} \frac{\partial P_e}{\partial s} \left[\frac{Re_r \, \zeta^3}{\mu_w \left(G'_w \left. \frac{\partial u}{\partial y} \right|_w \right)^3} \right]^{1/2} \right\}^2$$

ϵ_o is calculated as follows:

$$\epsilon_o = K_2 \, u_e \, Re_r \, \delta^*_{inc} \left[1 + 5.5 \quad \left(\frac{\tilde{y}}{\delta} \right)^6 \right]^{-1}$$

where $K_2 = .0168$, δ is the $\tilde{y}$ - location at which $u/u_e = .995$, and

$$\delta^*_{inc} = \zeta \int_0^{y_e} \left(1 - \frac{u}{u_e} \right) \frac{dy}{\zeta} .$$

The correspondence between the quantities defined above and the local subroutine variables is given below:

Physical Quantity	Program Variable
ϵ_i	EPSI
ϵ_o	EPSØ
K_1	BK1
K_2	BK2
α	BRKT
e^{β}	TERM
N	BN
δ	DELTA
δ^*_{inc}	DLSINC

The eddy viscosity calculation begins by finding δ, where $u/u_e = .995$. δ^*_{inc} is then evaluated using trapezoidal integration. The eddy viscisity loop starts near the wall with the auxiliary multipliers FIN = 1, and FØUT = 0. Both EPSI and EPSØ are evaluated and compared. If EPSI $<$ EPSØ, FIN and FØUT remain unchanged; however, if EPSI $\geq$ EPSØ, the routine sets FIN = 0. and FØUT = 1. through the rest of the boundary layer and EPSI is no longer calculated. The eddy viscosity at every mesh point can thus be set as follows:

EPS(I, JN) = FIN*EPSI + FØUT*EPSØ

Finally, in order to assure a smooth eddy viscosity profile across the boundary layer, ϵ at each interior point is recalculated as the average of the values calculated for that point and the four neighboring points, two on each side.

At the wall, the turbulent Prandtl number is given by

$$Pr_T = \frac{.4}{.44} \quad \frac{34}{26} \quad \frac{1}{Pr^{1/2}}$$

Elsewhere in the boundary layer,

$$Pr_T = \frac{.4}{.44} \left(\frac{1 - \exp \alpha}{1 - \exp \frac{26 \; Pr^{1/2} \alpha}{.34}} \right)$$

where α is as defined previously for ϵ_i.

Presently, the turbulent Lewis number Le_T is set to unity throughout the boundary layer.

SUBROUTINE ELEMTS

Subroutine ELEMTS solves the element conservation equation for a hydrogen-oxygen equilibrium case to obtain α, the mass fraction of hydrogen, at each mesh point in the boundary layer. The mass fraction of oxygen is then equal to $1 - \alpha$ at each mesh point. In normalized, finite-differenced form the element conservation equation is as follows:

$$A_1 \alpha_{m+1,n-1} + A_2 \alpha_{m+1,n} + A_3 \alpha_{m+1,n+1} = B$$

where

$$A_1 = \frac{Eu_{m,n}}{4\Delta y} - \frac{\rho v G'}{4\Delta y} + \frac{F}{2}\left[\left(G'\sigma_{5y} + \frac{G''}{G'}\sigma_5\right)\frac{1}{2\Delta y} - \frac{G'\sigma_5}{\Delta y^2}\right]$$

$$A_2 = \frac{\rho u}{\Delta s} + \frac{F G' \sigma_5}{\Delta y^2}$$

$$A_3 = -A_1 - \frac{F G' \sigma_5}{\Delta y^2}$$

$$B = \frac{\rho u \alpha_{m,n}}{\Delta s} - \frac{\rho v G'}{2}\alpha_{y_{m,n}} + \frac{F}{2}\left[\left(G'\sigma_{5y} + \frac{G''}{G'}\sigma_5\right)\alpha_{y_{m,n}} + G'\sigma_5 \alpha_{yy_{m,n}}\right] + \frac{E}{2}\alpha_{y_{m,n}} u_{m+1,n}$$

Here

$$E = \frac{\rho G' \zeta' \tilde{y}}{\zeta}, \quad F = \frac{G'}{\zeta^2}\frac{1}{Re_r},$$

$$\sigma_5 = \frac{\mu Le}{Pr} + \rho\epsilon\frac{Le_T}{Pr_T}.$$

The velocity $u_{m+1,n}$ in the expression for B has already been obtained by subroutine MØMNTM.

The hydrogen element equation boundary conditions are as follows. At the edge of the boundary layer,

$$\alpha = \alpha_e.$$

At the wall,

$$\left.\frac{\partial \alpha}{\partial y}\right|_w = A_0(\alpha_w - \alpha_{trans}),$$

where α_{trans} is the mass fraction of hydrogen in the transpiring gas (in, and

$$A_0 = \frac{Re_r \zeta^2 \dot{m}_w Pr_w}{G' \mu_w Le_w} .$$

Using a three-point derivative formula for $\left.\frac{\partial \alpha}{\partial y}\right|_w$, the wall boundary condition becomes

$$\frac{1}{2\Delta y}(-3\alpha_1 + 4\alpha_2 - \alpha_3) = A_0\alpha_1 - A_0\alpha_{trans}$$

$$\alpha_1 = \frac{4\alpha_2 - \alpha_3 + 2\Delta y A_0 \alpha_{trans}}{2\Delta y A_0 + 3} .$$

In subroutine ELEMTS, the correspondence between the program subscripts and the physical points in the boundary layer is the same as in subroutine MØMNTM.

The push-down storage technique explained in the description of subroutine MØMNTM is applied to the auxiliary array SIG5 (α_5) in subroutine ELEMTS.

Applying the differenced element equation at each interior point in the boundary layer results in a tridiagonal matrix of NY - 2 equations as in subroutine MOMNTM. To eliminate α_1 and α_{NY} as unknowns in the system of equations, the boundary conditions are applied. For the first equation in the matrix,

$$A(1,1)\,\alpha_1 + A(1,2)\,\alpha_2 + A(1,3)\,\alpha_3 = B(1)$$

Substituting the expression for α_1 obtained above from the wall boundary condition yields

$$\left[A(1,2) + \frac{4A(1,1)}{2\Delta y A_0 + 3}\right]\alpha_2 + \left[A(1,3) - \frac{A(1,1)}{2\Delta y A_0 + 3}\right]\alpha_3 =$$

$$\left[B(1) - \frac{A(1,1)\,2\Delta y\, A_0\, \alpha_{trans}}{2\Delta y\, A_0 + 3}\right]$$

Therefore we can set

$$A(1,2) = A(1,2) + \frac{4A(1,1)}{2\Delta y A_0 + 3}$$

$$A(1,3) = A(1,3) - \frac{A(1,1)}{2\Delta y A_0 + 3}$$

$$B(1) = B(1) - \frac{A(1,1)\ 2\Delta y\ A_0\ \alpha_{trans}}{2\Delta y\ A_0 + 3}$$

$$A(1,1) = 0.$$

For the last equation in the matrix

$$A(NY2,1)\ \alpha_{NY-2} + A(NY2,2)\ \alpha_{NY-1} + A(NY2,3)\ \alpha_{NY} = B(NY2)$$

The edge boundary condition is $\alpha_{NY} = \alpha_e$ so that we can set

$$B(NY2) = B(NY2) - A(NY2,3) * AFEDGE$$

$$A(NY2,3) = 0.$$

Subroutine TRIM is now called to solve for $\alpha_2, \alpha_3, \ldots, \alpha_{NY-1}$, and α_1 and α_{NY} are set according to the boundary conditions. Subroutine ELEMTS finally tests whether the hydrogen mass fraction profile obtained from the matrix solution asymptotically approaches α_e at the edge of the boundary layer. If

$$\left| \frac{1}{\alpha_e} \frac{\partial \alpha}{\partial y} \right|_e \leq \text{EPSLN3 (input)},$$

control returns to the calling routine; otherwise another mesh point is added at the edge. The mechanism of mesh point addition in subroutine ELEMTS is the same as in subroutine MØMNTM.

SUBROUTINE ENERGY

Subroutine ENERGY solves the energy equation to obtain the total enthalpy H and the enthalpy h at each mesh point in the boundary layer. In normalized, finite-differenced form the energy equation is as follows:

$$A_1 H_{m+1,n-1} + A_2 H_{m+1,n} + A_3 H_{m+1,n+1} = B' - C_1 u_{m+1,n-1} - C_2 u_{m+1,n} - C_3 u_{m+1,n+1}$$

where the velocities u_{m+1} on the right-hand side have been obtained already by subroutine MØMNTM, and

$$A_1 = \frac{E u_{m,n}}{4\Delta y} - \frac{\rho v G'}{4\Delta y} + \frac{F}{4\Delta y}\left(G'\sigma_{2y} + \frac{G''}{G'}\sigma_2\right) - \frac{FG'\sigma_2}{2\Delta y^2}$$

$$A_2 = \frac{\rho u}{\Delta s} + \frac{FG'\sigma_2}{\Delta y^2}$$

$$A_3 = -A_1 - \frac{FG'\sigma_2}{\Delta y^2}$$

$$B' = \frac{\rho u H_{m,n}}{\Delta s} - \frac{\rho v G'}{2} H_{y_{m,n}} + \frac{F}{2}\left[\left(G'\sigma_{2y} + \frac{G''}{G'}\sigma_2\right) H_{y_{m,n}} + G'\sigma_2 H_{yy_{m,n}}\right] + F\sum_i \left[\left(G'\sigma_{4y} + \frac{G''}{G'}\sigma_4\right) h_i c_{iy} + G'\sigma_4 (h_{iy} c_{iy} + h_i c_{iyy})\right]$$

$$C_1 = \frac{F}{2}\left(G'\sigma_{3y} + \frac{G''}{G'}\sigma_3\right)\frac{u_{m,n}}{2\Delta y} + \frac{FG'\sigma_3}{2\Delta y}\left(u_{y_{m,n}} - \frac{u_{m,n}}{\Delta y}\right)$$

$$C_2 = -\frac{E}{2} H_{y_{m,n}} - \frac{F}{2}\left(G'\sigma_{3y} + \frac{G''}{G'}\sigma_3\right) u_{y_{m,n}} - \frac{FG'\sigma_3}{2}\left(u_{yy_{m,n}} - \frac{2u_{m,n}}{\Delta y^2}\right)$$

$$C_3 = -C_1 - FG'\sigma_3 \frac{u_{m,n}}{\Delta y^2}$$

Here, $\sum_i$ is the summation over all species, and

$$E = \frac{\rho G' \zeta' \tilde{y}}{\zeta}, \quad F = \frac{G'}{\zeta^2} \frac{1}{Re_r}$$

$$\sigma_2 = \frac{\mu}{Pr} + \frac{\rho \epsilon}{Pr_T}, \quad \sigma_3 = \mu\left(1 - \frac{1}{Pr}\right) + \rho\epsilon\left(1 - \frac{1}{Pr_T}\right),$$

$$\sigma_4 = \frac{\mu}{Pr}(Le - 1) + \frac{\rho \epsilon}{Pr_T}(Le_T - 1)$$

The energy equation boundary conditions are

$H = H_w$ at the wall;

$H = H_e$ at the edge.

In subroutine ENERGY, the correspondence between the program subscripts and the physical points in the boundary layer is the same as in subroutine MØMNTM.

The push-down storage technique explained in the description of subroutine MØMNTM is applied to the auxiliary arrays SIG2 (σ_2), SIG3 (σ_3) and SIG4 (σ_4) in subroutine ENERGY.

Applying the differenced energy equation at each interior point in the boundary layer results in a tridiagonal matrix of NY-2 equations as in subroutine MØMNTM. To eliminate H_1 and H_{NY} as unknowns in the system of equations, the boundary conditions are applied. For the first equation in the matrix

$$A(1,1)\ H_1 + A(1,2)\ H_2 + A(1,3)\ H_3 = B(1)$$

(B(1) includes u_{m+1} terms as well as B'.)

The boundary condition at the wall is $H_1 = H_w$, so that

$$A(1,2)\ H_2 + A(1,3)\ H_3 = B(1) - A(1,1)\ H_w$$

Therefore, in the coefficient matrix we can set

$$B(1) = B(1) - A(1,1)*HWALL$$

$$A(1,1) = 0.$$

For the last equation in the matrix

$$A(NY2,1)\ H_{NY-2} + A(NY2,2)\ H_{NY-1} + A(NY2,3)\ H_{NY} = B(NY2)$$

The edge boundary condition is $H_{NY} = H_e$, so that

$$A(NY2,1)\ H_{NY-2} + A(NY2,2)\ H_{NY-1} = B(NY2) - A(NY2,3)*HEDGE$$

We can then set

$$B(NY2) = B(NY2) - A(NY2,3)\ *HEDGE$$

$$A(NY2,3) = 0.$$

Subroutine TRIM is now called to solve for H_2, H_3, ... , H_{NY-1}, and H_1 and H_{NY} are set according to the boundary conditions. The enthalpy h at each mesh point is then calculated as follows:

$$h_{m+1,n} = H_{m+1,n} - \frac{1}{2}\, u^2_{m+1,n}$$

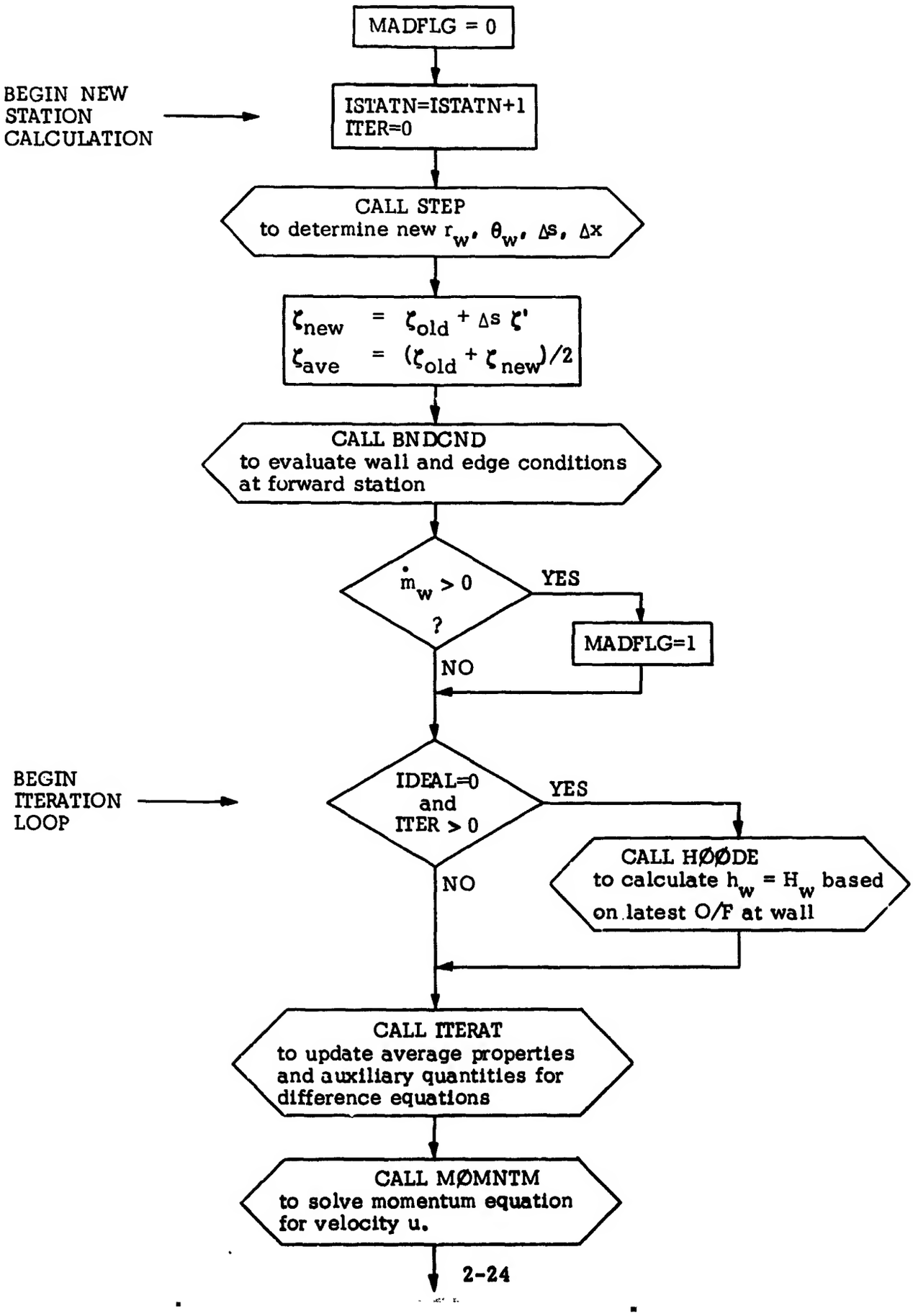
Subroutine ENERGY finally tests whether the total enthalpy profile obtained from the matrix solution asymptotically approaches H_e at the edge of the boundary layer. If

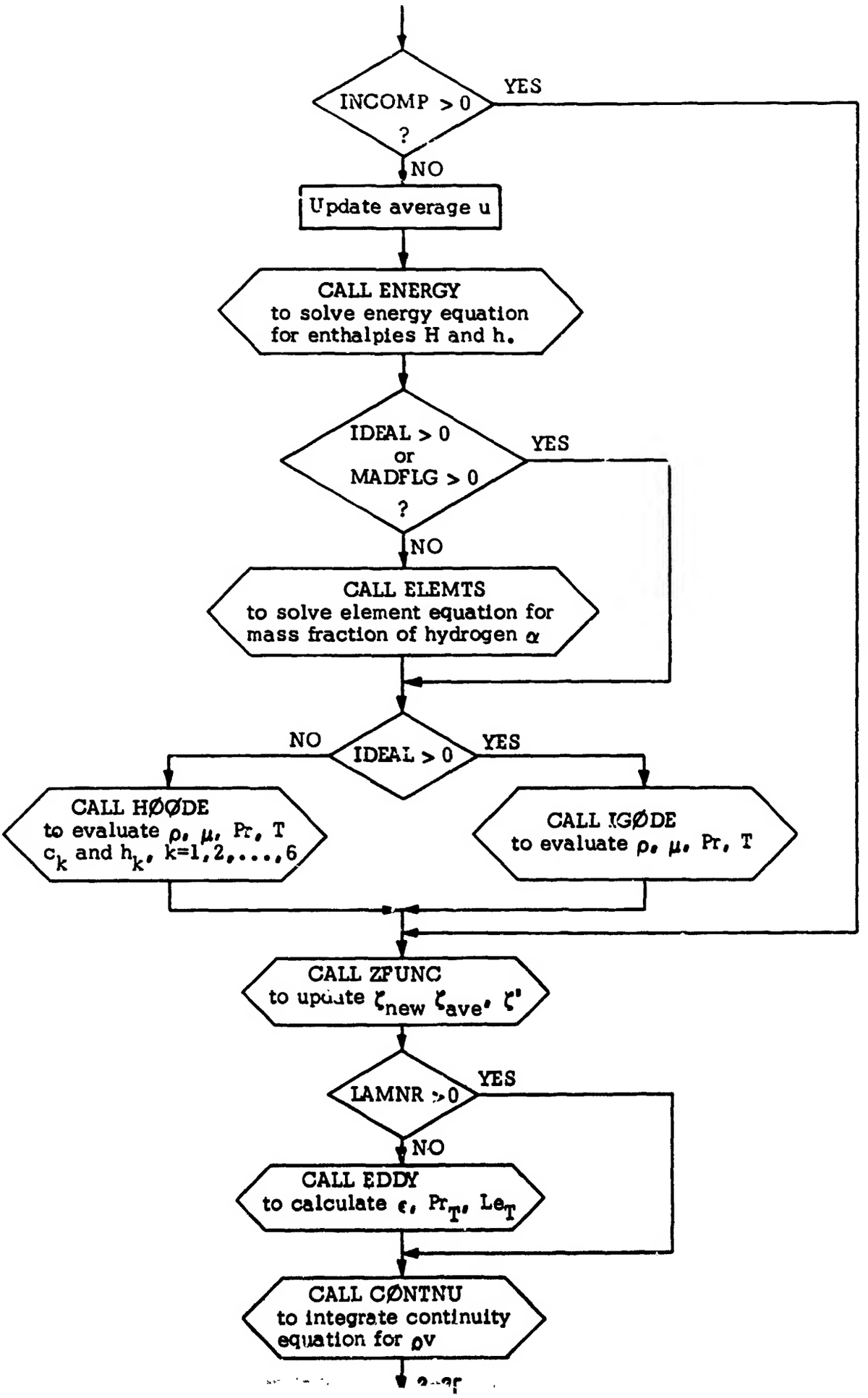
$$\left| \frac{1}{H_e} \left. \frac{\partial H}{\partial y} \right|_e \right| \leq \text{EPSLN2 (input)},$$

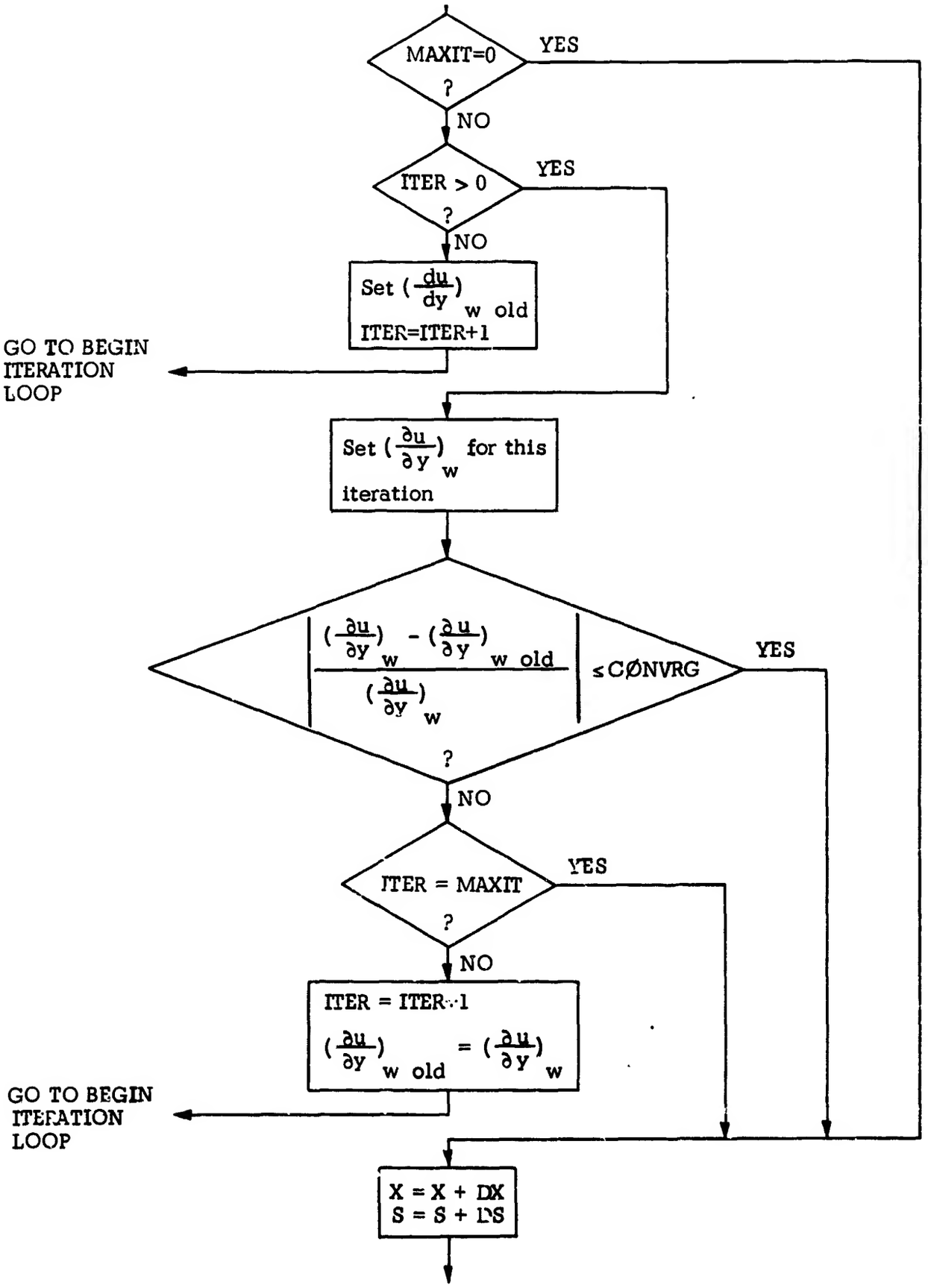
control returns to the calling routine; otherwise, another mesh point is added at the edge. The mechanism of mesh point addition in subroutine ENERGY is the same as in subroutine MØMNTM.

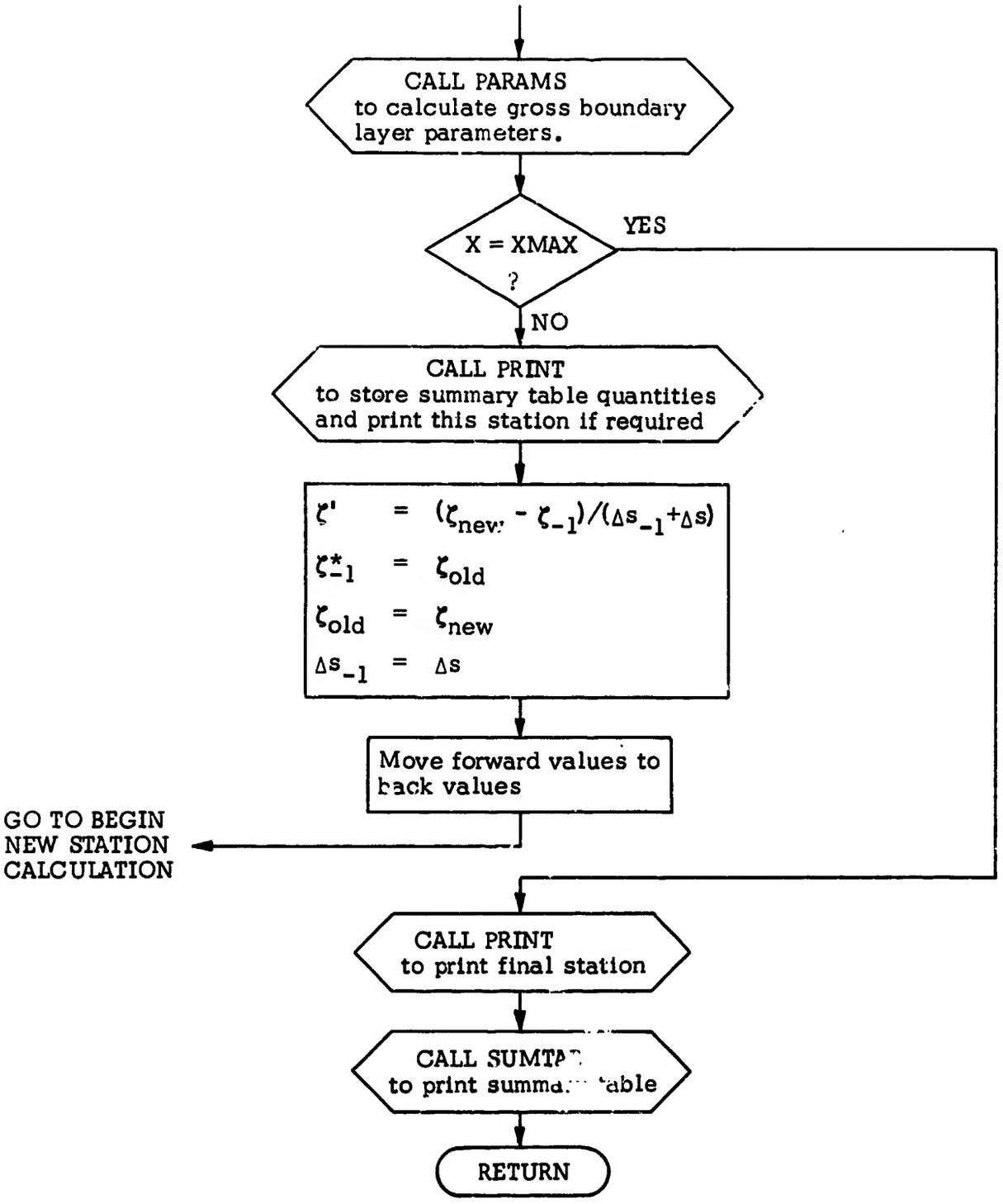
SUBROUTINE EXECUT

Subroutine EXECUT is the execution control routine for the Mass Addition Boundary Layer Program. Once the main program has completed all input processing and initialization, subroutine EXECUT is called to solve for the boundary layer properties from X = XINIT to X = XMAX. Subroutine EXECUT tests the input flags to call the appropriate subroutines for a given problem (perfect gas or equilibrium, laminar or turbulent, compressible or incompressible) and checks for convergence of the iterations at a given station. Following is a flowchart showing the logic in subroutine EXECUT in detail.


MADFLG = 0
BEGIN NEW STATION CALCULATION
ISTATN=ISTATN+1
ITER=0
CALL STEP
to determine new r_w, θ_w, Δs, Δx
$\zeta_{new} = \zeta_{old} + \Delta s\ \zeta'$
$\zeta_{ave} = (\zeta_{old} + \zeta_{new})/2$
CALL BNDCND
to evaluate wall and edge conditions at forward station
$\dot{m}_w > 0$?
YES
MADFLG=1
NO
BEGIN ITERATION LOOP
IDEAL=0 and ITER > 0
YES
CALL HØØDE
to calculate $h_w = H_w$ based on latest O/F at wall
NO
CALL ITERAT
to update average properties and auxiliary quantities for difference equations
CALL MØMNTM
to solve momentum equation for velocity u.


INCOMP > 0 ?
YES
NO
Update average u
CALL ENERGY
to solve energy equation
for enthalpies H and h.
IDEAL > 0
or
MADFLG > 0
?
YES
NO
CALL ELEMTS
to solve element equation for
mass fraction of hydrogen α
NO
IDEAL > 0
YES
CALL HØØDE
to evaluate ρ, μ, Pr, T
c_k and h_k, k=1,2,...,6
CALL IGØDE
to evaluate ρ, μ, Pr, T
CALL ZFUNC
to update ζ_{new} ζ_{ave}, ζ'
LAMNR > 0
YES
NO
CALL EDDY
to calculate ε, Pr_T, Le_T
CALL CØNTNU
to integrate continuity
equation for ρv


MAXIT=0 ?
YES
NO
ITER > 0 ?
YES
NO
Set $(\frac{du}{dy})_{w\ old}$
ITER=ITER+1
GO TO BEGIN ITERATION LOOP
Set $(\frac{\partial u}{\partial y})_{w}$ for this iteration
$\left|\frac{(\frac{\partial u}{\partial y})_{w} - (\frac{\partial u}{\partial y})_{w\ old}}{(\frac{\partial u}{\partial y})_{w}}\right| \leq CONVRG$?
YES
NO
ITER = MAXIT ?
YES
NO
ITER = ITER+1
$(\frac{\partial u}{\partial y})_{w\ old} = (\frac{\partial u}{\partial y})_{w}$
GO TO BEGIN ITERATION LOOP
X = X + DX
S = S + DS


CALL PARAMS
to calculate gross boundary layer parameters.
X = XMAX ?
YES
NO
CALL PRINT
to store summary table quantities and print this station if required
$\zeta' = (\zeta_{new} - \zeta_{-1})/(\Delta s_{-1}+\Delta s)$
$\zeta^*_{-1} = \zeta_{old}$
$\zeta_{old} = \zeta_{new}$
$\Delta s_{-1} = \Delta s$
Move forward values to back values
GO TO BEGIN NEW STATION CALCULATION
CALL PRINT
to print final station
CALL SUMTAB
to print summary table
RETURN

SUBROUTINE GFUNC

Subroutine GFUNC is called during problem initialization to set up the relationship between the normal boundary layer coordinate $\bar{y}$ and the non-dimensional coordinate y, based on information specified in the program input. y and $\bar{y}$ are related as follows:

$$y = G(\tilde{y}) \quad \text{where} \quad \tilde{y} = \frac{\bar{y}}{L\,\zeta(s)}.$$

Here G is a general stretching function which is uniquely specified by input quantities; L is the input reference length BLREF; ζ is the boundary layer normalization function.

The form of G is as follows:

$$y = G(\tilde{y}) = b\left\{ \left[\log\left((e-1)\left(\frac{\tilde{y}}{b} + \alpha\right) + 1\right)\right]^{1/n} - \beta \right\}$$

where $b = \tilde{y}_e$, n is the input quantity SN3, and α and β are computed such that

$G(0) = 0$ and
$G'(0) = GP\emptyset$ (input).

Subroutine GFUNC begins by calculating $\tilde{y}_e = \delta_I/(L\zeta)$, where δ_I is the input initial boundary layer thickness DELTAI, and ζ is the initial value of the boundary layer normalization function.

The following arrays are constructed for the maximum possible number of points across the boundary layer:

Y - y at each mesh point;
YTIL - $\tilde{y}$ at each mesh point;
(Then $\bar{y} = \tilde{y}\,L\,\zeta(s)$.)
BGP - G' (y);
BGPP - G" (y).

If SN3 = 0 (nominal value if not input), then no stretching has been specified, and

$$y_e = \tilde{y}_e;$$

$$\Delta y = \frac{y_e}{NYI}$$ where NYI is the input initial number of mesh point intervals across the boundary layer;

$y = \tilde{y}$ everywhere;

$G'(\tilde{y}) = 1;$

$G''(\tilde{y}) = 0.$

If SN3 $\neq 0$, then α and β must be calculated. To find α, a function F is defined as follows:

$$G_0(\tilde{y}) = b\left[\log\left((e-1)\,\frac{\tilde{y}}{b} + 1\right)\right]^{1/n}$$

- the function G when $\alpha = 0$ and $\beta = 0$.

$$G_0'(\tilde{y}) = \frac{e-1}{n}\left[\log\left((e-1)\,\frac{\tilde{y}}{b} + 1\right)\right]^{1/n-1} \frac{1}{(e-1)\,\frac{\tilde{y}}{b} + 1}$$

$$F(\tilde{y}) = G_0'(\tilde{y}) - GP\emptyset$$

Newton-Raphson iteration is applied to solve for $\tilde{y}_\alpha$ such that $F(\tilde{y}_\alpha) = 0$. If the solution does not converge in 100 iterations, subroutine DEBUG is called to indicate the error in GFUNC and terminate execution. Otherwise, when $\tilde{y}_\alpha$ is found,

$$\alpha = \frac{\tilde{y}_\alpha}{b}.$$

Correspondingly,

$$\beta = \left[\log\left((e-1)\,\alpha + 1\right)\right]^{1/n}.$$

Once α and β are calculated, the precise G-function is known and the arrays Y, YTIL, BGP, and BGPP are constructed as follows:

$$y_e = G(\tilde{y}_e) \text{ where } \tilde{y}_e = \frac{\delta_I}{L\,\zeta}$$

$$\Delta y = \frac{y_e}{NYI}$$

$$\left.\begin{aligned} &Y(I) = y_i = (I-1)\ \Delta y \\ &YTIL(I) = G^{-1}(y_i) \\ &BGP(I) = G'(\tilde{y}_i) \\ &BGPP(I) = G''(\tilde{y}_i) \end{aligned}\right\} \quad I = 1, 2, \ldots, \text{max. \# points}$$

Subroutine GFUNC also stores the initial values of the following boundary layer quantities and counters:

YTEDGE = $\tilde{y}_e$

YEDGE = y_e

DY = Δy (constant throughout the program)

YTZETA = $\tilde{y}_\zeta = 1$, the point where $\frac{\bar{y}}{L} = \zeta$

YZETA = y_ζ corresponding to $\tilde{y}_\zeta$

NY = NYI + 1, the initial number of mesh points in the boundary layer and the index of the edge point.

NY1 = NY-1

NY2 = NY-2

Finally, if a stretching function G has been specified (SN3 $\neq 0$), the arrays Y, YTIL, BGP, and BGPP are printed out by subroutine GFUNC.

SUBROUTINE HØØDE

Subroutine HØØDE provides the interface between the boundary layer subroutines and the equilibrium subroutines. Whenever the equilibrium properties at a given mesh point or group of mesh points are required for a hydrogen-oxygen case, subroutine HØØDE is called from the boundary layer routines with an argument which indicates the type of equilibrium solution to be performed (i.e., isentropic expansion, temperature-pressure calculation, etc.). Subroutine HØØDE in turn calls the appropriate equilibrium subroutine to obtain the required solution. HØØDE also converts quantities from units used in the boundary layer routines (pressure in lb_f/ft^2, temperature in °R, etc.) to equilibrium units (pressure in atm., temperature in ° K, etc.) and back again.

The calling sequence is as follows:

CALL HØØDE (ICALL)

where

ICALL	is an input flag equal to 1, 2, 3, or 4 indicating the type of equilibrium calculations to be performed.

The effect of each of the possible values of ICALL is discussed in turn.

ICALL=1

This is the initialization call. If IDEAL=0 in the DATA namelist, subroutine HØØDE is called from the main program with ICALL=1. Subroutine HØØDE in turn calls subroutine ØDE, which initializes the equilibrium storage areas and causes the THERMØ data and REACTANTS data to be read. HØØDE also evaluates the necessary unit conversion constants for use in later calls.

No equilibrium solution results from this call to HØØDE.

ICALL=2

Subroutine HØØDE is called during initialization with ICALL=2 to perform an isentropic expansion at the edge of the boundary layer. Using the input values of PEDGE, TEDGE, and AFEDGE, HØØDE calls subroutine TPCALC to perform a temperature-pressure equilibrium calculation. This establishes an entropy SO and an enthalpy h_e = SHEDGE. Then H_e, which is constant along the edge of the boundary layer, is given by

$$H_e = \text{HEDGE} = \text{SHEDGE} + \text{UEDGE} * \text{UEDGE}/2.$$

Then, holding entropy constant and proceeding through the input pressure table PETAB, subroutine HØØDE calls subroutine SPCALC to do up to thirteen entropy-pressure calculations at a time, obtaining a value of h_e = SHE from each calculation. From these calculations, an edge velocity table UETAB is obtained; for a given point IX in the pressure table,

UETAB (IX) = SQRT (2.*(HEDGE - SHE))

ICALL=3

Subroutine HØØDE is called every iteration to do a temperature-pressure calculation at the wall. Using TWALL, PEDGE, and an Ø/F ratio based on the latest iterated value of α_w, HØØDE calls subroutine TPCALC to obtain a value of h_w = SHWALL. Then H_w = HWALL = SHWALL.

ICALL=4

Subroutine HØØDE is called every iteration with ICALL=4 after the main dependent variables u, H, h, α, and ρv have been obtained across the boundary layer. The purpose of this call is to obtain values of ρ, μ, Pr, T, and h_k and c_k for each species at every mesh point. Enthalpy-pressure equilibrium calculations are performed only at every IYEQth mesh point (including the wall and edge points); the equilibrium properties at the intermediate points are obtained by interpolation using subroutine PHØENX. Subroutine HØØDE calls subroutine HPCALC to perform thirteen enthalpy-pressure calculations at a time until the edge of the boundary layer is reached. Subroutine PHØENX is then called for the arrays RHØ, SMU, PRNØ, and TEM (The latter two arrays are named PR and T in the other boundary layer subroutines.) to interpolate for the missing values. The species mass fractions c_k and species enthalpies h_k are not interpolated when Le=1 and Le_T=1, because the terms which contain them then drop out of the boundary layer equations.

[illegible]

[illegible]

[illegible]

where

T	[illegible]
[illegible]	[illegible]
P	is the pressure [illegible]
[illegible]	[illegible]
	= [illegible] and the temperature T is to be calculated.
	= [illegible] and the enthalpy [illegible] is to be calculated.
[illegible]	is the density ρ calculated by [illegible].
[illegible]	is the viscosity μ calculated by [illegible].
PR	is the Prandtl number Pr returned by [illegible].

Subroutine IGØDE performs the following calculations:

$$R = \frac{\Re}{\mathfrak{M}}$$ where $\Re$ = 49721.011 and $\mathfrak{M}$ is the input molecular weight FMØLWT.

$$C_p = \frac{\gamma R}{\gamma - 1}$$ where γ is the input specific heat ratio GAMMA.

If h and P are given (ITPHP = 0),

$$T = \frac{h}{C_p}$$

If T and P are given (ITPHP = 1),

$$h = C_p T$$

Finally ρ, μ, and Pr are calculated as follows:

$$\rho = \frac{P}{RT}$$

$$\mu = 2.27 \times 10^{-8} \frac{T^{1/2}}{(1 + \frac{198.6}{T})}$$

Pr = PRI where PRI is the input Prandtl number.

SUBROUTINE ITERAT

This subroutine prepares for an iteration on the boundary layer difference equations by calculating averages of the various properties at each mesh point across the boundary layer. For each property at a given mesh point, the average of the value at the previous station and the latest iterated value is computed and stored for use in calculating the difference equation coefficients. For example, for density at mesh point I,

$$\text{RH}\emptyset\ (I, JA) = 0.5 * (\text{RH}\emptyset\ (I, J\emptyset) + \text{RH}\emptyset\ (I, JN))$$

Here RHØ (I, JA) is the computed average, RHØ (I, JØ) the value at the previous station, and RHØ (I, JN) the latest iterated value. At the beginning of a new station calculation, RHØ (I, JØ) and RHØ (I, JN) will be equal so that the average value will initially be equal to the value at the previous station.

Properties whose averages are calculated and stored by ITERAT are u, H, α, $1-\alpha$, h, ρ, μ, Pr, Le, T, ϵ, Pr_T, and Le_T.

Subroutine ITERAT also calculates, at each mesh point across the boundary layer, the auxiliary quantities

$$E = \frac{\rho\, G' \zeta' \tilde{y}}{\zeta} \quad \text{and} \quad F = \frac{G'}{\zeta^2}\ \frac{1}{\text{Re}_r}\ .$$

Finally, ITERAT calculates and stores the temporary quantities σ_1, σ_2, σ_3, σ_4, and σ_5 at the first and second mesh points to initialize the push-down storage feature used by the difference equation solution subroutines MØMNTM, ENERGY, and ELEMTS.

SUBROUTINE LCURV

Subroutine LCURV performs linear interpolation in a table which may contain discontinuities and saves the place in the table. LCURV is used to obtain the wall temperature T_w from a table of T_w versus x and the mass addition $\dot{m}_w$ from a table of $\dot{m}_w$ versus x.

The calling sequence is as follows:

CALL LCURV (X, XTAB, YTAB, NP, IX, Y)

where

X	is the argument.
XTAB	is the argument table and contains the independent variables stored in increasing order. When tabulating discontinuous functions, the argument is repeated at the point of discontinuity.
YTAB	is the function table, where YTAB(I) is the value of the dependent variable corresponding to the argument value in XTAB(I).
NP	is the number of entries in XTAB and YTAB.
IX	is a pointer which, upon input, is the position at which the argument search is to begin. Upon return from LCURV, IX is set such that XTAB(IX-1) < X ≤ XTAB(IX). By using the output value of IX as the input value for the next call to LCURV, the place in the table is saved. If IX ≤ 0 or IX ≥ NP, the search will start at the beginning or end of the table, respectively.
Y	is the function value obtained by interplation.

Subroutine LCURV defines an arithmetic statement function Q as follows:

$$Q(x_{k-1}, y_{k-1}, x_k, y_k) = y_{k-1} + (x-x_{k-1}) \frac{y_k - y_{k-1}}{x_k - x_{k-1}}$$

LCURV then merely searches the table to locate the interval containing the argument x and uses Q to linearly interpolate between the two surrounding table points for the function value Y. If X falls exactly on a discontinuity, Y is set to the corresponding function value on the high-x side of the discontinuity.

If X falls outside the table, LCURV linearly extrapolates using the first two or last two table entries.

If NP = 1, then LCURV sets Y = YTAB(1). A constant table may thus be specified by entering only YTAB(1).

SUBROUTINE MØMNTM

Subroutine MØMNTM solves the momentum equation to obtain the velocity u at each mesh point in the boundary layer. In normalized, finite-differenced form, the momentum equation is as follows:

$$A_1 u_{m+1,n-1} + A_2 u_{m+1,n} + A_3 u_{m+1,n+1} = B$$

where

$$A_1 = \frac{E u_{m,n}}{4\Delta y} - \frac{\rho v G'}{4\Delta y} + \frac{F}{4\Delta y}\left(\frac{G''}{G'}\sigma_1 + G'\sigma_{1y}\right) - \frac{F G' \sigma_1}{2\Delta y^2}$$

$$A_2 = \frac{\rho u}{\Delta s} - \frac{E u_{y_{m,n}}}{2} + \frac{F G' \sigma_1}{\Delta y^2}$$

$$A_3 = -A_1 - \frac{F G' \sigma_1}{\Delta y^2}$$

$$B = \rho u \frac{u_{m,n}}{\Delta s} - \frac{\rho v G'}{2} u_{y_{m,n}} + \rho u \frac{du_e}{ds} +$$

$$\frac{F}{2}\left[\left(\frac{G''}{G'}\sigma_1 + G'\sigma_{1_y}\right) u_{y_{m,n}} + G'\sigma_1 u_{yy_{m,n}}\right]$$

Here

$$E = \frac{\rho G' \zeta' \tilde{y}}{\zeta}, \quad F = \frac{G'}{\zeta^2}\frac{1}{Re_r}, \quad \sigma_1 = \mu + \rho\epsilon.$$

The momentum equation boundary conditions are

$u = 0$ at the wall;

$u = u_e$ at the edge.

The features of subroutine MØMNTM described below apply equally to the energy and element conservation equation solutions in subroutines ENERGY and ELEMTS, respectively.

Subscripting

In evaluating the coefficients of the difference equations, the correspondence between the program subscripts and the physical points in the boundary layer is as follows:

s - direction

JN = m+1

JØ = m

JA = m+1/2 (average of m and m+1)

y - direction

I+1 = n+1

I = n

I-1 = n-1

Push-Down Storage

The auxiliary quantity σ_1, unlike F and F, is not precalculated and stored at each mesh point. Rather, a push-down storage technique is used. When the difference equation at a mesh point I is being evaluated, only the σ_1's at I and the two surrounding points I-1 and I+1 are needed because

$$\sigma_{1y_n} = \frac{\sigma_{1_{n+1}} - \sigma_{1_{n-1}}}{2\Delta y} .$$

The code is set up so that $\sigma_{1_{n-1}}$ and σ_{1_n} are already available as SIG1(1) and SIG1(2), respectively. (Upon entry to subroutine MØMNTM, for I=2, SIG1(1) and SIG1(2) have been appropriately calculated in subroutine ITERAT.) Then, for evaluating the coefficients at mesh point I, SIG1(3) is first evaluated as

SIG1(3) = SMU(I+1,JA) + RHO(I+1,JA)*EPS(I+1,JA)

All σ_1's necessary for calculating the momentum equation coefficients at mesh point I are now available. Before going on to mesh point I+1, the σ_1's are repositioned in their temporary array as follows:

SIG1(1) = SIG1(2)

SIG1(2) = SIG1(3)

The procedure is then repeated at I+1.

Matrix Solution

The differenced momentum equations, when applied at each mesh point in the boundary layer, constitute a system of linear equations whose matrix of coefficients is tridiagonal. Specifically, the matrix is constructed by applying the difference equation at mesh points 2, 3, 4, ..., NY-2, NY-1, where point 1 is the wall and point NY the edge of the boundary layer. Since the momentum equation is not applied at the wall point or edge point, there will be NY-2 rows in all in the matrix, and the elements A(I-1,1), A(I-1,2), A(I-1,3), and B(I-1) will contain A_1, A_2, A_3, and B, respectively, for mesh point I.

The wall and edge boundary conditions are figured into the first and last equations in the matrix, so that there will be as many unknowns as equations. For the first equation in the matrix

$$A(1,1)\ u_1 + A(1,2)\ u_2 + A(1,3)\ u_3 = B(1)$$

The boundary condition at the wall is $u_1 = 0$, so that

$$A(1,2)\ u_2 + A(1,3)\ u_3 = B(1).$$

Therefore, in the coefficient matrix, we can set

$$A(1,1) = 0.$$

For the last equation in the matrix

$$A(NY2,1)\ u_{NY-2} + A(NY2,2)\ u_{NY-1} + A(NY2,3)\ u_{NY} = B(NY2)$$

The edge boundary condition us $u_{NY} = u_e$, so that

$$A(NY2,1)\ u_{NY-2} + A(NY2,2)\ u_{NY-1} = B(NY2) - A(NY2,3)\ u_e$$

We can then set

$$B(NY2) = B(NY2) - A(NY2,3)*UEDGE$$

$$A(NY2,3) = 0$$

Subroutine MØMNTM now calls subroutine TRIM to solve for $u_2, u_3, \ldots, u_{NY-1}$ and sets $u_1 = 0$ and $u_{NY} = u_e$ in accordance with the boundary conditions.

Point Addition

After the momentum equation solution, subroutine MØMNTM tests whether the velocity profile obtained asympototically approaches u_e at the edge of the boundary layer. If

$$\left| \frac{1}{u_e} \frac{\partial u}{\partial y} \right|_e \leq \text{EPSLN1 (input)},$$

control returns to the calling routine. Otherwise, subroutine ADDPT is called to add one mesh point at the edge of the boundary layer and set all properties at the new point. Upon return to MØMNTM, the difference equations are applied at the last two interior mesh points from the new edge point, the edge boundary condition is reapplied, and subroutine TRIM is called to solve the new system of equations. This process is repeated until the edge test is satisfied; however, if more than five points must be added or the maximum possible number of points in the boundary layer is reached, subroutine DEBUG is called to print a message indicating the error in MØMNTM and terminate execution.

SUBROUTINE NLØUT

This routine prints the combined data from the DATA and TDKINP namelists in a format which is organized for easy reference by the user. All single-cell variables are printed first in their various categories, followed by the tabular data. The output from subroutine NLØUT is in general self-explanatory; however, the various input catagories are listed below in the order in which they appear, with explanatory comments where appropriate.

Single-Cell Variables

All single-cell variables appear on a single page, each in the format

name = value.

Where no value was input by the user, the nominal or default value is printed. These variables are organized in the following categories:

(1) Flags and options.
Possible input values and their meanings are given in the output for each flag.

(2) Problem limits and initial values.

(3) Reference quantities.

(4) Input normalization factors.

(5) Edge quantities.

(6) Constants.

(7) Convergence and edge criteria.

(8) Counters.

Tabular Data

For each table, the table length is printed first, followed by the dependent variable array and the independent variable array in adjacent columns.

The tables are grouped under the following categories:

(1) Stepsize control tables.

(2) Wall tables.

(3) Geometry and edge tables.
If the wall contour and pressure tables were entered in the TDKINP namelist, they will be printed here as RWTAB, XTABRW, PETAB, and XTABPE.

(4) Experimental profiles.
This page will appear only if experimental profiles for u and h were input.

SUBROUTINE PARAMS

Subroutine PARAMS is called at each station of the boundary layer solution to evaluate the displacement thickness δ^*, momentum thickness θ, and other profile parameters of interest, based on the converged solution at that station. The quantities calculated and the method of calculation are summarized here.

(1) Mass addition correction to displacement thickness:

$$\text{ADDMAS} = \int_{s_{init}}^{s} \dot{m}_w \zeta r_w^j \, ds$$

Trapezoidal integration is used.

(2) Displacement thickness:

$$\delta^* = L\left\{\zeta \int_0^{y_e} \left(1 - \frac{\rho u}{\rho_e u_e}\right) \frac{dy}{G'} + \frac{\text{ADDMAS}}{\rho_e \, u_e \, r_w}\right\}$$

The integral over y is evaluated using Simpson's rule

(3) Throat radius corrected for displacement thickness:

$$r^{*\prime} = r^* L - \delta^* \cos \theta_w$$

Once the boundary layer solution passes the throat (specified by the value input for XSTAR), the normalized throat radius $r^* = r^*/L$ and θ_w at the throat are obtained by interpolation from the input wall contour table. δ^* at the throat is obtained by interpolating between the values of δ^* calculated at the last two stations.

(4) Momentum thickness:

$$\theta = L\zeta \int_0^{y_e} \frac{\rho u}{\rho_e \, u_e} \left(1 - \frac{u}{u_e}\right) \frac{dy}{G'}$$

The integral over y is evaluated using Simpson's rule.

(5) Skin friction calculated by integrating the momentum equation:

$$\tau_I = -\frac{\mu_r u_r}{L\zeta} \int_0^{y_e} \frac{1}{F}\left[\rho u \frac{\partial u}{\partial s} + (\rho v G' - uE)\frac{\partial u}{\partial y} + \frac{dP_e}{ds}\right] dy$$

where

$$E = \rho \frac{G'\zeta'\tilde{y}}{\zeta} \; ; \; F = \frac{G'}{\zeta^2}\frac{1}{Re_r} .$$

The integral over y is evaluated using Simpson's rule. (τ_I is evaluated for diagnostic purposes only and does not appear in the summary table.)

(6) Wall shear stress:

$$\tau_w = \mu_r u_r \frac{G'}{L\zeta} \mu_w \left.\frac{\partial u}{\partial y}\right|_w$$

A parabolic wall derivative is used.

(7) Local shear stress coefficient:

$$C_f = \frac{G'}{\zeta Re_r} \frac{\mu_w \left.\frac{\partial u}{\partial y}\right|_w}{\frac{1}{2}\rho_e u_e^2}$$

A parabolic wall derivative is used.

(8) Heat transfer rate:

$$-q_w = \frac{\mu_r u_r^2 G'}{L\zeta} \frac{\mu_w}{Pr_w} \left[\left.\frac{\partial h}{\partial y}\right|_w + (Le-1)\sum_k h_k \left.\frac{\partial c_k}{\partial y}\right|_w\right]$$

A parabolic wall derivative is used.

(9) Stanton number:

$$St = \frac{G'}{\zeta Re_r} \frac{1}{\rho_e u_e (H_e - H_w)} \frac{\mu_w}{Pr_w} \left[\left.\frac{\partial h}{\partial y}\right|_w + (Le-1)\sum_k h_k \left.\frac{\partial c_k}{\partial y}\right|_w\right]$$

A parabolic wall derivative is used.

(10) Integral of heat transfer rate:

$$Q_w = -(2\pi)^j L^{j+1} \int_{s_{init}}^{s} q_w r_w^j \, ds$$

The integral over s is evaluated using the trapezoidal rule.

SUBROUTINE PHØENX

Subroutine PHØENX takes an array in which every nth value is known and, given an argument array, interpolates for the missing values in the array. The calling sequence is as follows:

CALL PHØENX (V,Y,N,L)

where

V	is the dependent variable array, and V(1), V(N+1), V(2*N+1), . . . , V(L) are known (previously calculated) values in this array.
Y	is the independent variable (argument) array such that Y(I) is the argument value corresponding to V(I), whether or not V(I) is known.
N	is the interval (integer) at which values in the array V are given.
L	is the length of the arrays V and Y.

Subroutine PHØENX first packs every Nth value (including the last value) from the arrays V and Y into the auxiliary arrays F and X, respectively, thereby generating a table of V versus Y. Subroutine XNTERP is then called to interpolate for each of the missing values in V, using their corresponding Y-values as arguments.

Subroutine PHØENX is used as a means of reducing the execution time for hydrogen-oxygen equilibrium cases. The equilibrium properties are solved at every nth mesh point rather than at every point, and PHØENX is used to interpolate for values of the equilibrium properties at the remaining points.

SUBROUTINE PRINT

Subroutine PRINT is called at the end of every station in the boundary layer solution to store the summary table quantities for that station, write a summary table record on scratch unit IDRUM if it is time to do so, produce a printout of the boundary layer profiles if it is time to do so, and advance the print station counters before the boundary layer solution proceeds to the next station.

Subroutine PRINT first stores all summary table quantities for this station into the proper row of the array SUMARY. If NSTA rows of SUMARY are now full or if this is the last station of the boundary layer solution, the contents of SUMARY are written onto logical unit IDRUM to be read and printed later by subroutine SUMTAB. (See Description of Program Output for a detailed description of the quantities printed in the summary table.)

The print station counters are then tested. If ILPRNT=NLPRNT, it is time to print the GROUP I profiles, and ILPRNT is accordingly set to zero. If ISPRNT= NSPRNT, it is time to print the Group II profiles, and ISPRNT is set to zero. (See Description of Program Input for explanations of NLPRNT and NSPRNT. See Description of Program Output for details of the Group I and Group II profiles.) If this is the initial station, the final station, or an XLIM station, ILPRNT and ISPRNT will have been set to zero outside of subroutine PRINT.

If ILPRNT is now zero, the main boundary layer parameters and the Group I profiles are printed at this station. For an equilibrium case ISPRNT is tested and, if it is zero, the Group II profiles are printed.

Whether or not the profiles are printed, subroutine PRINT advances the print station counters ILPRNT and ISPRNT by one before returning to the calling routine, subroutine EXECUT.

SUBROUTINE PRØFIL

This subroutine calculates profiles at the initial station of the dependent variables u, H, h, α, and ρv across the boundary layer.

If experimental profiles are input for u, h, and α, then the values of these dependent variables at each mesh point are obtained by interpolating in the input tables UPRØF vs YBYNU, HPRØF vs YBYNH, and APRØF vs YBYNA, respectively. Then $H = h + u^2/2$ at each mesh point.

If experimental profiles are not input, the velocity profile between $0.1\,\tilde{y}_e$ and $0.9\,\tilde{y}_e$ is calculated according to the input power law (See PLAW in the Description of Program Input):

$$u = u_e \left(\frac{\tilde{y}}{0.9\tilde{y}_e}\right)^{\frac{1}{PLAW}} .$$

Between the wall and $0.1\tilde{y}_e$, a linear velocity curve is fared into the power law profile; $u = u_e$ between $0.9\tilde{y}_e$ and $\tilde{y}_e$.

For an incompressible case, $h = h_w$ at each mesh point, and $H = h_w + u^2/2$. For a compressible case,

$$H = H_w + \frac{u}{u_e}(H_e - H_w).$$

Then $h = H - u^2/2$.

The initial α-provile, if not input, is calculated as follows:

$$\alpha = \alpha_w + \frac{u}{u_e}(\alpha_e - \alpha_w),$$

where α_w and α_e are the input quantities AFWALL and AFEDGE.

Finally, at each mesh point,

$$\rho v = \dot{m}_w + \frac{\tilde{y}}{\tilde{y}_e} .$$

Subroutine PRØFIL then sets back values of the dependent variables equal to their forward values initially.

SUBROUTINE RDTAPE

A restart capability exists in the Mass Addition Boundary Layer Program and is described in the section on Additional Program Features.

Subroutine RDTAPE is called at the beginning of a restart case to read previously saved data for the proper station from the restart tape (logical unit ITAPE). Since data for a series of stations may be saved on the tape, subroutine RDTAPE reads the value of the station counter from the beginning of each logical record and compares it to the desired station IRSRD. If the correct station is located, the tape is backspaced to the beginning of the record and the restart data is read. If data for station IRSRD is not present, the following message is printed:

THERE IS NO RESTART DATA FOR STATION [IRSRD].

The case is then terminated.

SUBROUTINE STEP

Subroutine STEP is called at the beginning of a new station calculation to determine the stepsize Δs to be used and to obtain the wall contour properties r_w, $\frac{dr_w}{dx}$, and θ_w at the next station.

Subroutine STEP first moves the forward values of r_w, $\frac{dr_w}{dx}$, and θ_w to their back positions, since the current x-position will now become the back station. Thus

THW(1) = THW(2)

RW(1) = RW(2)

DRWDX(1) = DRWDX(2)

The stepsize Δs is given by

$$\Delta s = \frac{DX}{\cos \theta_w}$$

where DX is determined from the series of criteria explained below.

(1) If

$$X + 10^{-6} \geq XLIM(IDX)$$

then at the last station the stepsize was set to hit x = XLIM(IDX), and the next stepsize is specified by

DX = DXLIM(IDX).

The pointer IDX is incremented by one to indicate the next XLIM - value to be reached. DX, if obtained here, is not altered by any subsequent criteria except possibly (5).

(2) If criterion (1) above did not govern the stepsize selection, subroutine STEP compares X with XTABSK(ISK). If X < XTABSK(ISK), then SKTAB(ISK) is the k-factor to be used in determining the next stepsize. If X ≥ XTABSK(ISK), then it is time to change to a new k-factor; the pointer ISK is incremented by one, and X is compared with the new XTABSK(ISK). This process is repeated, if necessary, until X < XTABSK(ISK).

Then DX is set equal to the previous stepsize time the k-factor:

$$DX = DX*SKTAB(ISK).$$

(3) If this is the first station calculation,

$$DX = DXI \text{ (input)}.$$

(4) DX, determined from criterion (2), is checked to see whether it exceeds the next XLIM-value to be reached. If

$$X + DX + 10^{-6} < XLIM(IDX),$$

DX is unchanged; otherwise subroutine STEP sets

$$DX = XLIM(IDX) - X,$$

so that the solution will reach XLIM(IDX) exactly. The print flags are also set so that a printout will occur at the forward station.

(5) Finally, DX is checked to see whether it exceeds XMAX. If

$$X + DX + 10^{-6} < XMAX,$$

DX is unchanged; otherwise, subroutine STEP sets

$$DX = XMAX - X.$$

After determining DX from one of the above criteria and setting the stepsize $\Delta s = DX/\cos \theta_w$, STEP calls subroutine XNTERP, with X + DX as the argument, to obtain RW(2) and DRWDX(2), the values at the forward station of r_w and $\frac{dr_w}{dx}$, respectively. Finally,

$$THW(2) = \theta_w = \tan^{-1} \frac{dr_w}{dx}.$$

SUBROUTINE SUMTAB

Subroutine SUMTAB is called at the end of a case or (by subroutine DEBUG) when a fatal error is encountered to read records of summary table data from logical unit 17 and print the summary table as part of the program output.

The summary table data is saved up in core and written on unit 17 several stations at a time by subroutine PRINT. The summary table contains the values of the main boundary layer parameters of interest at each station. The exact format of the summary table output and the items contained in it are described in the section on program output.

The integer flags, counters, and constants in subroutine SUMTAB have the following interpretations:

IDRUM	-	Fortran logical unit on which summary table data is written. (=17)
NREC	-	Number of logical records of data currently on unit IDRUM.
NSTA	-	Number of stations per logical record of summary table data. (=13)
ISTA	-	Number of stations of data currently saved in core and not yet written on unit IDRUM.
NVAR	-	Number of variables per station. (=29)

Subroutine SUMTAB first checks if there are any stations of data in core (in the array SUMARY) which have not yet been written on unit IDRUM. If ISTA is non-zero, which may be the case if a fatal error has been encountered, SUMTAB writes a logical record of ISTA stations of data before rewinding unit IDRUM.

Subroutine SUMTAB then reads and prints each record on unit IDRUM in turn. One logical record on unit IDRUM corresponds to one page of summary table output.

The quantities $(\bar{r}_w - \delta^* \cos\theta)$ and $\bar{x}$, the tenth and twentieth items of data for a given station, are divided by RSTPR, the throat radius corrected for displacement thickness, before being printed, so that these data may be used for the corrected wall contour table input to the Two-Dimensional Kinetics Program (Reference 1). If the nozzle throat was not reached in this case, RSTPR will be unity.

SUBROUTINE TABLES

This subroutine is called from the main program at the beginning of a case to convert the input tables to their normalized forms and obtain the wall and edge conditions at the initial station. Where quantities are needed at the back station, subroutine TABLES sets those quantities equal to the values at the initial station.

Subroutine TABLES replaces values of $\bar{x}/x_N$ in the argument arrays XTABRW, XTABSK, XLIM, XTABMD, XTABTW, and XTABPE by corresponding $\bar{x}/L$ values. Values of $\bar{r}_w/x_N$ in the dependent variable array RWTAB are also normalized. Subroutine TABLES then obtains from the input tables the initial values of r_w, $\frac{dr_w}{dx}$, θ_w, Δx, Δs, $\dot{m}_w$, and T_w.

Pressure and edge velocity tables are handled differently for a hydrogen-oxygen case and for a perfect gas case. These are described in turn.

Hydrogen-Oxygen Equilibrium Case

For an equilibrium case, a pressure table PETAB vs XTABPE has been input, either in the DATA namelist or in the TDKINP namelist as PITAB vs. XITAB. (Since PITAB and XITAB are equivalenced to PETAB and XTABPE in the main program, the pressure table can always be referenced as PETAB vs. XTABPE.) Subroutine TABLES calls subroutine HØØDE to do an isentropic expansion at the edge of the boundary layer to obtain a normalized edge velocity table UETAB vs. XTABPE. (See subroutine HØØDE for details.) Subroutine HØØDE is also called to perform a temperature-pressure equilibrium calculation at the wall, giving initial values of h_w and H_w.

Perfect Gas Case

For a perfect gas case, subroutine TABLES calls subroutine IGØDE with the initial value of T_w and the input value PEDGE to obtain $\bar{h}_w$. Then $h_w = \bar{h}_w/u_r^2$ and $H_w = h_w$. The enthalpy at the edge of the boundary layer is obtained similarly. Subroutine IGØDE is called with the input initial values TEDGE and PEDGE to obtain the initial values of $\bar{h}_e$ and $\bar{\rho}_e$. Then $h_e = \bar{h}_e/u_r^2$ and

$$H_e = h_e + \frac{u_e^2}{2},$$

where u_e is the normalized initial edge velocity, obtained from the input value UEDGE:

$$u_e = \text{UEDGE} \cdot \frac{u_N}{u_r} .$$

For a perfect gas case, either an edge pressure table PETAB vs. XTABPE or an edge velocity table UETAB vs. XTABPE may be input. If a pressure table was input, a velocity table is generated point for point from it as follows (The subscript 0 here denotes the initial station.):

$$h_e = h_{e0} \left(\frac{\overline{P}_e}{\overline{P}_{e0}}\right)^{\frac{\gamma - 1}{\gamma}},$$

$$u_e = \left(2 (H_e - h_e)\right)^{1/2}.$$

If a velocity table was input, a pressure table is generated from it as follows:

$$\overline{P}_e = \overline{P}_{e0} + \frac{1}{2} \overline{\rho}_e (u_{e0}^2 - u_e^2) u_r^2,$$

where $\overline{\rho}_e$, the edge density, was obtained from subroutine IGODE above.

Velocity Derivative Table

At this point, for an equilibrium or perfect gas case, both a velocity table and a pressure table are available. The initial value of the edge velocity UEDGE is now obtained by interpolation in the table UETAB vs. XTABPE (whether input or calculated as described above). The edge velocity table is printed out; then a velocity derivative table DUDXT vs. XTDUDX is generated in its place. A linear derivative is taken between two velocity table points i and i + 1:

$$\frac{du_e}{dx} = \frac{u_{e_{i+1}} - u_{e_i}}{x_{i+1} - x_i} .$$

This is then stored in the velocity derivative table as the value of $\frac{du_e}{dx}$ at

$$x = \frac{1}{2} (x_i + x_{i+1}).$$

Each set of points in the velocity table UETAB vs. XTABPE is treated in this manner.

Finally, the initial value of $\frac{du_e}{dx}$ is obtained by linear interpolation in the new table DUDXT vs. XTDUDX, and

$$\frac{du_e}{ds} = \frac{du_e}{dx} \cos \theta_w .$$

The initial value of edge pressure PEDGEB is then obtained by interpolation, and control returns to the main program.

MAIN PROGRAM (TFCBL)

The Mass Addition Boundary Layer Program main driver is responsible for reading and processing the program input and obtaining all boundary layer quantities at the initial station, X = XINIT. At this point, subroutine EXECUT, the main execution control subroutine, is called to integrate along the boundary layer from X = XINIT to X = XMAX.

The main program code also contains a master list of all common blocks used throughout the boundary layer subroutines.

Specifically, the main program does the following (in sequence):

(1) Sets program constants.

(2) Sets nominal values of input data.

(3) Reads the DATA namelist input.

(4) Reads the TDKINP namelist input if it is present.

(5) Calls subroutine NLØUT to print the program input.

(6) Calls subroutine HØØDE, for an equilibrium case, to read the THERMØ and REACTANTS data and initialize the equilibrium portion of the program.

(7) Sets constants whose values are based on input data.

(8) Initializes the independent variables x and s and the boundary layer normalization function ζ.

(9) Calls subroutine TABLES to normalize the input tables, and evaluate the boundary layer wall and edge conditions at the initial station.

(10) Initializes the derivative ζ' of the boundary layer normalization function.

(11) Calls subroutine GFUNC to evaluate the boundary stretching function G and set up arrays of y, $\tilde{y}$, G', and G" at each mesh point.

(12) Calls subroutine PRØFIL to obtain initial values of the main dependent variables u, h, H, α, and ρv at each mesh point.

(13) Calls subroutine IGØDE for a perfect gas case or subroutine HØØDE for an equilibrium case to initialize the thermodynamic and laminar transport properties at each mesh point.

(14) Presets turbulent quantities for a laminar case or calls subroutine EDDY to calculate the turbulent transport properties at each mesh point for a turbulent case.

(15) Moves forward values to back values. (Both are equal at the initial station.)

(16) Calls subroutine PARAMS to calculate the gross boundary layer parameters at the initial station.

(17) Calls subroutine PRINT to print the results of the above initial station calculations.

(18) Calls subroutine EXECUT to solve for all boundary layer quantities from X = XINIT to X = XMAX.

(19) Following completion of the boundary layer solution, prints the throat radius corrected for displacement thickness.

(20) Calculates and prints the thrust loss, if the ambient pressure was input.

SUBROUTINE TRIM

This subroutine solves the system

$$\bar{\bar{A}}\bar{X} = \bar{b}$$

for $\bar{X}$ where $\bar{\bar{A}}$ is tridiagonal, i.e.;

$$\text{all } a_{ij} = 0 \quad \text{if} \quad i > j+1 \quad \text{or} \quad i < j-1.$$

The method used is Gaussian elimination.
The calling sequence is as follows:

CALL TRIM (A,X,B,N,NN)

where

A Is the input coefficient matrix and must be dimensioned at least A(N,3). The elements a_{ij} must be input as

$$\begin{bmatrix} — & A(1,2) & A(1,3) \\ A(2,1) & A(2,2) & A(2,3) \\ A(3,1) & A(3,2) & A(3,3) \\ & \vdots & \\ A(N,1) & A(N,2) & — \end{bmatrix} = \begin{bmatrix} — & a_{11} & a_{12} \\ a_{21} & a_{22} & a_{23} \\ a_{32} & a_{33} & a_{34} \\ & \vdots & \\ a_{n,n-1} & a_{nn} & — \end{bmatrix}$$

The contents of A are preserved by TRIM.

X Is the output solution vector $\bar{X}$ and must be dimensioned at least X(N).

B Is the input vector $\bar{b}$ and must be dimensioned at least B(N). The contents of B are preserved by TRIM.

N Is the order of the system. $N \geq 2$ is required.

NN Is the dimension of A (NN, 3), X(NN), and B(NN) in the calling program.

Subroutine TRIM is called (1) by subroutine MØMNTM to solve the momentum equation for velocity at each mesh point in the boundary layer, (2) by subroutine ENERGY to solve the energy equation for total enthalpy H at each point, and (3) by subroutine ELEMTS to solve the element conservation equation for α, the element mass fraction of hydrogen, at each point.

SUBROUTINE XNTERP

Given a table of n points of independent variables x_i and dependent variable y_i, XNTERP returns a value of y and its first derivative y' for a given value of x and saves the place in the table.

Subroutine XNTERP is used widely throughout the program, specifically in the following contexts:

(1) To interpolate in tables of r_w versus x, P_e versus x, and u_e versus x.

(2) To generate initial profiles across the boundary layer for u and h from input experimental data.

(3) To interpolate in arrays of y and $\tilde{y}$.

(4) To obtain thermodynamic and laminar transport properties at mesh points intermediate to those for which the equilibrium chemistry was solved explicitly. (See subroutine PHØENX.)

The calling sequence is as follows:

CALL XNTERP (XIN, YØUT, YPØUT, IXIN, XAR, YAR, IAR, CAR, IPØS)

where

XIN is the input value of the argument x.

YØUT is the value of the dependent variable y returned.

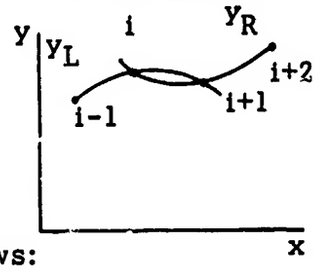
YPØUT is the value of the first derivative y' returned.

IXIN is a pointer which is set by XNTERP upon return to the calling program, such that XAR(IXIN) is the largest entry in the independent variable list XAR which is less than or equal to the argument XIN. This pointer must be initialized at zero prior to the first call to XNTERP for a given table.

XAR is the array of independent variables x_i stored in increasing order.

YAR	is the array of dependent variables y_i corresponding to the x_i.
IAR	is the number of values in XAR and YAR.
CAR	is a vector of six cells used by XNTERP to store the coefficients of the parabolas used for interpolation. (No user initialization is necessary.)
IPØS	is a pointer, set by the user as follows: = 0 on the first entry to XNTERP for a given table; = the subscript, on subsequent entries, of the independent variable array XAR at which the argument search is to begin.

Subroutine XNTERP searches the independent variable table until the points bracketing x are found ($x_i < x < x_{i+1}$). Using the four surrounding points x_{i-1}, x_i, x_{i+1}, and x_{i+2}, XNTERP evaluates the coefficients of parabolas y_L, passing through the three leftmost points, and y_R, passing through the three rightmost points.



$$y_L = C_1 + C_2 (x-x_{i-1}) + C_3 (x-x_{i-1})^2$$

$$y_R = C_4 + C_5 (x-x_i) + C_6 (x-x_i)^2$$

A cubic weighting function α is then defined as follows:

$$U(x) = \frac{x - x_i}{x_{i+1} - x_i}$$

$$\alpha(x) = 3U^2-2U^3$$

$$\alpha'(x) = (6U-6U^2)\ U'(x)$$

Finally y and y' are calculated:

$$y = (1-\alpha)\ y_L + \alpha y_R$$

$$y' = (1-\alpha)\ y'_L - \alpha' y_L + \alpha' y_R + \alpha y'_R$$

If the argument x is between the first two or the last two points in the table, only one parabola is used. In a two point table, linear interpolation is used. For a single point, y is constant for all x, and only YAR(1) need be specified.

Subroutine XNTERP will not extrapolate in a table of four or more points. Rather, the following error message is printed:

XNTERP ØUT ØF RANGE ... X = _____ X(1) = _____ X(N) = _____
Y(1) = _____ Y(N) = _____

XNTERP then calls subroutine SUMTAB to print the summary table thus far and finally calls EXIT, terminating execution.

Subroutine XNTERP is programmed to take maximum advantage of the searches and calculations performed on the previous entry to it. Through use of the pointer IXIN, XNTERP, once it locates the argument in the table, ascertains whether either or both sets of parabola coefficients from the last entry can be reused and, if so, does not recalculate those coefficients. The user can further enhance the subroutine's efficiency if he has some foreknowledge of where the argument lies in the independent variable table. For example, if it is known that the argument is monotonically increasing, then the begin-search pointer IPØS can be set equal to IXIN following return to the calling program so that for the next interpolation the argument search will begin at XAR (IXIN), where it left off on the previous entry. An even simpler way to do this is to make the actual arguments for IXIN and IPØS the same variable.

This subroutine is the same as that used to interpolate in the contour and pressure tables in the ICRPG Turbulent Boundary Layer Program (Reference 2).

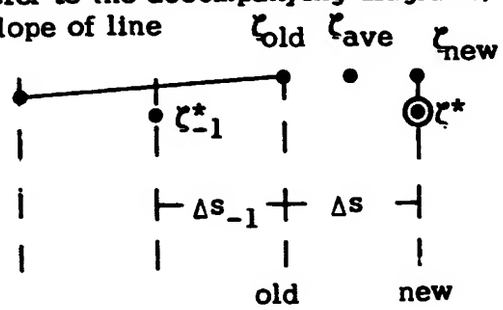
SUBROUTINE ZFUNC

Subroutine ZFUNC iteratively calculates the value of the boundary layer normalization function ζ and its derivative ζ'. Although the non-iterative portions of the ζ-calculations take place in subroutine EXECUT and not in subroutine ZFUNC, the entire method is explained here for clarity.

The quantities involved in the ζ-calculation and their corresponding program symbols are given in the following table:

Quantity	Symbol
ζ^*_{-1}	ZSTAR(1)
Δs_{-1}	DSZ(1)
ζ_{old}	ZETAØ
ζ_{ave}	ZETA
ζ_{new}	ZETAN
ζ'	ZETAP
ζ^*	ZSTAR(3)

At the beginning of a new station calculation the quantities ζ^*_{-1}, ζ_{old}, ζ', Δs_{-1}, and Δs are known. (Refer to the accompanying diagram.)



Subroutine EXECUT obtains a value of ζ_{new} for iteration 0 by integrating ζ':

$$\zeta_{new} = \zeta_{old} + \zeta' \Delta s.$$

Then

$$\zeta_{ave} = (\zeta_{old} + \zeta_{new})/2.$$

The boundary layer equations are solved, using this value of ζ_{new}, to obtain u, H, h and α at each mesh point.

Subroutine EXECUT then calls subroutine ZFUNC to update ζ' and ζ_{new}. Subroutine ZFUNC proceeds as follows:

(1) y_ζ, the value of y where $u = 0.99\, u_e$, is obtained by interpolation.

(2) $\tilde{y}_\zeta$, the corresponding value of $\tilde{y}$, is found by interpolating in the table of y vs $\tilde{y}$.

(3) A corrected value of ζ is calculated:

$$\zeta^* = \zeta_{new}\, \tilde{y}_\zeta$$

(4) ζ' and ζ_{new} are recalculated as follows:

$$\zeta' = (\zeta^* - \zeta^*_{-1})/(\Delta s_{-1} + \Delta s);$$

$$\zeta_{new} = \zeta_{old} + \zeta' \Delta s.$$

Also,

$$\zeta_{ave} = (\zeta_{old} + \zeta_{new})/2.$$

(5) $\dot{m}_{w_{m+1/2}}$ is recalculated, based on $\dot{m}_{w_{m+1}}$ normalized by the updated value of ζ_{new}. ($\rho v = \dot{m}_{w_{m+1/2}}$ is the wall boundary condition for the continuity equation, which is solved following execution of subroutine ZFUNC.)

If additional iterations are performed at a given station, subroutine ZFUNC is called every iteration to recalculate ζ', ζ_{new}, and ζ_{ave} based on the latest iterated velocities.

At the end of a station, subroutine EXECUT updates the remaining ζ-related quantities to prepare for the next station calculation. Specifically,

$$\zeta' = (\zeta_{new} - \zeta^*_{-1})/(\Delta s_{-1} + \Delta s)$$

$$\zeta^*_{-1} = \zeta_{old}$$

$$\zeta_{old} = \zeta_{new}$$

$$\Delta s_{-1} = \Delta s$$

The boundary layer solution then proceeds to the next station.

3. DICTIONARY OF PROGRAM VARIABLES

All program variables of principal importance are defined in this section, with the exception of those quantities which are input. The variables are grouped according to function.

SUBSCRIPTS

Symbol	Meaning
NY	Number of points in boundary layer (≤ 250).
JØ	Back station m.
JN	Forward station m+1.
JA	Average of back and forward stations (m+1/2).
NEL	Number of chemical elements (≤ 2).
NSP	Number of chemical species, (≤ 6).
I	Mesh point subscript, ranging from 1 (wall) to NY (edge).
J	Station subscript, taking on the values JØ, JN, and JA.
IEL	Element subscript for equilibrium case: =1 for hydrogen (fuel); =2 (NEL) for oxygen (oxidant).
ISP	Species subscript for equilibrium case: =1 for H; =2 for H_2; =3 for H_2O; =4 for O; =5 for OH; =6 (NEL) for O_2.

LOGICAL UNITS

Symbol	Meaning
IDRUM	Logical unit on which summary table data is temporarily stored (=17).
ITAPE	Logical unit on which restart data is saved (=16).

COUNTERS

Symbol	Meaning
ISTATN	Station number.
ITER	Iteration number (reset to zero at beginning of each station).
ILPRNT	Number of stations since Group I profiles were last printed.
ISPRNT	Number of stations since Group III profiles were last printed.
LNSPPG	Maximum number of lines per page of output.
LINESR	Number of lines remaining for output on current page.

ANALYTIC QUANTITIES

The analytic variables are described below in alphabetical order. Dimensioned variables appear with subscripts. Variable subscripts take on the meanings given above under SUBSCRIPTS. Where a constant appears as a subscript, it represents the maximum dimension of the variable.

Symbol	Meaning
A(I, 3)	Array containing the difference equation coefficients. Each column of A represents a diagonal of the tridiagonal matrix.
AFEDGE	α_e, mass fraction of hydrogen at the edge of the boundary layer.
AFWALL	α_w, mass fraction of hydrogen at the wall.
ALPHA(I, J, IEL)	Element mass fraction.
AV(I)	Sound speed.
B(I)	Right-hand side of difference equations.
BCF	C_f, local shear stress coefficient.
BGP(I)	$G'(\tilde{y})$, first derivative of the boundary layer stretching function.
BGPP(I)	G"(y), second derivative of the boundary layer stretching function.
BLE(I, J)	Le, Lewis number.
BLET(I, J)	Le_T, turbulent Lewis number.
DLSTAR	δ^*, displacement thickness.
DLSTTH	δ^*_{th}, displacement thickness at the throat.
DPEDSN	$\left.\frac{dP_e}{ds}\right\|_{m+1} = -\rho_{e_{m+1}} u_{e_{m+1}} \left.\frac{du_e}{ds}\right\|_{m+1}$
DRWDX(2)	$\left.\frac{dr_w}{dx}\right\|_m$ and $\left.\frac{dr_w}{dx}\right\|_{m+1}$
DS	Δs, wetted length stepsize.
DUEDS	$\left.\frac{du_e}{ds}\right\|_{m+1/2}$

DUEDSN	$\left.\frac{du_e}{ds}\right\|_{m+1}$
DUEDSØ	$\left.\frac{du_e}{ds}\right\|_{m}$
DX	Δx, axial stepsize.
DY	Δy, spacing between mesh points.
E(I)	E, auxiliary quantity in difference equations.
EPS	ϵ, eddy viscosity.
F(I)	F, auxiliary quantity in difference equations.
H(I, J)	H, total enthalpy.
HEDGE	H_e, total enthalpy at the edge of the boundary layer.
HWALL	H_w, total enthalpy at the wall.
ØDYSQ	$\frac{1}{(\Delta y)^2}$
Ø2DY	$\frac{1}{2\Delta y}$
Ø4DY	$\frac{1}{4\Delta y}$
PEDGEB	$\bar{P}_e$, unnormalized edge pressure.
PR(I, J)	Pr , Prandtl number.
PRT(I, J)	Pr_T, turbulent Prandtl number.
REYINF	Re_r, reference Reynolds number.
RHØ(I, J)	ρ, density.
RHØV(I)	$(\rho v)_{m+1/2}$
RSTPR	r*', throat radius corrected for displacement thickness.

RW(2)	r_{w_m} and $r_{w_{m+1}}$, wall radius at the back and forward stations.
S	s, wetted length.
SCI(I, J, ISP)	c_k, species mass fraction.
SH(I, J)	h, enthalpy.
SHEDGE	h_e, enthalpy at the edge of the boundary layer.
SHI(I, J, ISP)	h_k, species enthalpy.
SHWALL	h_w, enthalpy at the wall.
SIG1 (3) SIG2 (3) SIG3 (3) SIG4 (3) SIG5 (3)	Temporary storage for σ_1, σ_2, σ_3, σ_4, and σ_5, auxiliary quantities in the difference equations.
SMDW	$\dot{m}_{w_{m+1/2}}$, mass addition rate.
SMDWN	$\dot{m}_{w_{m+1}}$, mass addition rate.
SMDWØ	$\dot{m}_{w_m}$, mass addition rate.
SMU(I, J)	μ, viscosity.
SNTGRL	$\int_{\bar{s}_{init}}^{\bar{s}} \dot{m}_w \zeta r_w^j \, ds$, part of the mass addition correction to the displacement thickness.
SQW	$-q_w$, heat transfer rate.
SQWDS	$-(2\pi)^j \int_{\bar{s}_{init}}^{\bar{s}} (\bar{r}_w)^j q_w \, d\bar{s}$
STAN	Stanton number.

T(I, J)	T, temperature.
TAUW	τ_w, wall shear stress.
TEDGE	T_e, edge temperature.
THETA	θ, momentum thickness.
THW(2)	θ_{w_m} and $\theta_{w_{m+1}}$, wall contour angle at the back and forward stations.
TWALL	T_w, wall temperature.
U(I, J)	u, velocity in the s-direction.
UEDGE	u_e, velocity at the edge of the boundary layer.
X	x, axial distance.
Y(I)	y, non-dimensional normal coordinate.
YTIL(I)	$\tilde{y} = \frac{\bar{y}}{L\zeta}$, normal coordinate.
ZETA	$\zeta_{m+1/2}$, boundary layer normalization function.
ZETAN	ζ_{m+1}, boundary layer normalization function.
ZETAØ	ζ_m, boundary layer normalization function.
ZETAP	ζ' derivative of the boundary layer layer normalization function.

4. DESCRIPTION OF PROGRAM INPUT

Program input for the Mass Addition Boundary Layer Program is in four parts: (1) the case title; (2) the DATA namelist; (3) optionally, the TDKINP namelist for wall contour and pressure tables which have been punched from the Two-Dimensional Kinetics Program (Reference 1); (4) for a hydrogen-oxygen equilibrium case, the THERMØ data and REACTANTS data for the one-dimensional equilibrium chemistry calculations. These are described in turn.

CASE TITLE

The first card contains the case title in columns 1-60, to appear at the top of each page of output.

DATA NAMELIST

This group of input follows the standard NAMELIST format. The first card of this group must contain $DATA starting in column 2. The last card must contain $END starting in column 2.

All program input may be entered in this group; however, if pressure and wall contour tables have been punched from TDK, these must be entered in the TDKINP namelist described later.

The input variables and arrays in the DATA namelist are described in functional groups below. For some of the variables, nominal values are preset in the program and will be used if not overridden by an input value. Where applicable the nominal values are indicated.

Flags and Options

Name	Description
IDEAL	Integer flag, set as follows: =1 (nominal) for a perfect gas case; =0 for a hydrogen-oxygen system with equilibrium chemistry.
LAMNR	Integer flag, set as follows: =1 for laminar flow; =0 (nominal) for turbulent flow.
INCØMP	Integer flag, set as follows: =1 for incompressible flow; =0 (nominal) for compressible flow.
J2D	Integer flag, set as follows: =1 (nominal) for axisymmetric geometry; =0 for a two-dimensional case.
INTDK	Integer flag, set as follows: =1 if pressure and wall contour tables are input from TDK, in which case the TDKINP namelist will follow the DATA namelist; =0 (nominal) if pressure and wall contour tables are input within the DATA namelist. (No TDKINP namelist will be present.)

Reference Quantities

Name	Description
BLREF	L, reference length in ft. (Nominal value = 1.)
UREF	u_r, reference velocity in ft/sec. (Nominal value = 1.)
RHØREF	ρ_r, reference density in $lb_f sec^2/ft^4$. (Nominal value = 1.)
SMUREF	μ_r, reference viscosity in $lb_f sec/ft^2$. (Nominal value = 1.)

Input Normalization Constants

If data to be input to the Mass Addition Boundary Layer Program exists in a nondimensional form (e.g. a nozzle contour table may have been normalized by throat radius), it need not be dimensionalized prior to input. The following input normalization constants are used by the program to multiply the input values to which they correspond immediately after the data is read.

Name	Description
XN (ft.)	x_N, normalization factor by which $\bar{x}$-distances and lengths have been normalized upon input. (Nominal value =1.) The following input variables and arrays are assumed by the program to be normalized by XN: SINIT, XINIT, XMAX Stepsize control tables XLIM, XTABSK Argument tables XTABTW, XTABMD, XTABRW, XTABPE
YN (ft.)	y_N, normalization factor by which the experimental profile argument tables YBYNU, YBYNH, and YBYNA have been normalized upon input. (Nominal value =1.)
UEN (ft/sec.)	u_N, normalization factor by which the velocity UEDGE and edge velocity table UETAB have been normalized upon input. (Nominal value =1.)
PEN (lb_f/ft^2.)	P_N, normalization factor by which the pressure PEDGE and edge pressure table PETAB have been normalized upon input. (Nominal value =1.)

Name	Description
SMDN (lb_f sec/$ft.^3$)	$\dot{m}_N$, normalization factor by which the mass addition table SMDTAB has been normalized upon input. (Nominal value = 1.)

Problem Limits and Initial Values

Name	Description
SINIT	$\bar{s}_{init}/x_N$, initial value of wetted length $\bar{s}$ at which boundary layer solution begins. (Nominal value = 0.)
XINIT	$\bar{x}_{init}/x_N$, initial value of axial distance $\bar{x}$ at which boundary layer solution begins. (Nominal value = 0.)
XMAX	$\bar{x}_{max}/x_N$, final value of axial distance $\bar{x}$ at which boundary layer solution terminates.
DXI	$\Delta x_{init} = \frac{\Delta \bar{x}_{init}}{L}$, initial stepsize (normalized).
DELTAI (ft.)	δ, initial boundary layer thickness, in units of $\bar{y}$.
ZETAPI	Initial value of ζ', the derivative of the boundary layer normalization function ζ. If no value is input, the program will calculate one.

Edge Quantities

Name	Description
UEDGE	$\bar{u}_e/u_N$, edge velocity at initial station.
PEDGE	$\bar{P}_e/P_N$, edge pressure at initial station.
TEDGE (°R)	T_e, edge temperature at initial station.
AFEDGE	α_e, constant mass fraction of hydrogen at the edge of the boundary layer for a hydrogen-oxygen case. (Do not enter for a perfect gas case). Mixture ratio, MR = $(1-\alpha_e)/\alpha_e$

Constants

Name	Description
AFTRNS	α_{trans}, mass fraction of hydrogen in the transpiring gas. (Do not input for a perfect gas case.)
PRI	Optional input Prandtl number Pr. If input, this constant value will be used for either a perfect gas or hydrogen-oxygen case. If not input for a perfect gas case, Pr = .72 throughout. For the hydrogen-oxygen system, a variable Pr calculated by the One-Dimensional Equilibrium (ODE) subroutines will be used if PRI is not input.
GAMMA	γ, specific heat ratio for a perfect gas case. (Do not input for an H_2-O_2 equilibrium case).
FMØLWT	M, molecular weight for a perfect gas case. (Do not input for an H_2-O_2 equilibrium case).
PLAW	Exponent parameter p in velocity power law initial profile: $\frac{u}{u_e} = \left(\frac{\tilde{y}}{0.9\tilde{y}_e}\right)^{1/p}$, $0.1\tilde{y}_e \le \tilde{y} \le 0.9\tilde{y}_e$. If PLAW is not input and experimental initial profiles are not used, a power law velocity profile with p = 1 will be generated. If experimental profiles are input, do not enter a value for PLAW.
PAMB	P_{amb}/P_N, ambient pressure for final thrust loss calculation. If not input, a thrust loss calculation will not be performed.
GPØ*	G' (0), the value desired for the derivative $G'(\tilde{y}) = \frac{dy}{d\tilde{y}}$ of the stretching function at $\tilde{y} = 0$. (Do not input if no stretching is desired).

*The use of a stretching function for the normal coordinate is required for turbulent boundary layers, but is optional for laminar flows.

Name	Description
SN3	Exponent parameter n for the boundary layer stretching function $y = G(\tilde{y}) = b\left\{\left[\log(1.718(\frac{\tilde{y}}{b} + \alpha) + 1)\right]^{1/n} - \beta\right.$ If not input, no stretching will be used, i.e. $y = G(\tilde{y}) = \tilde{y}$; $G'(\tilde{y}) = 1$; $G''(\tilde{y}) = 0$.
XSTAR	$\bar{x}/x_N$ at the throat.
AFWALL	α_w, initial mass fraction of hydrogen at the wall. (Do not input for a perfect gas case.) For a hydrogen-oxygen equilibrium case, if AFWALL is not input, the program will set AFWALL=AFTRNS.
UEK (ft/sec)	$\bar{u}_{ek}$, non-equilibrium edge velocity at the final station of the boundary layer solution (from TDK), for use in the thrust loss calculation. If UEK is not input, the equilibrium edge velocity will be used in the thrust loss calculation.
RHØEK (lb_f sec^2/ft^4)	$\bar{\rho}_{ek}$, non-equilibrium edge density at the final station of the boundary layer solution (from TDK), for use in the thrust loss calculation. If RHØEK is not input, the equilibrium edge density will be used in the thrust loss calculation.

Convergence and Edge Criteria

Name	Description
CØNVRG	Convergence criterion for iterations on the boundary layer solution at a given station. If the percentage change in $\left.\frac{\partial u}{\partial y}\right\|_w$ between successive iterations is less than or equal to CØNVRG, the solution will proceed to the next station. (Nominal value = .005).
EPSLN1	If, after a given solution of the momentum equation, $\left\|\frac{1}{u_e}\ \left.\frac{du}{dy}\right\|_e\right\| > \text{EPSLN1}$, the boundary layer thickness is increased by adding an additional mesh point at the edge.
EPSLN2	If, after a given solution of the energy equation, $\left\|\frac{1}{h_e}\ \left.\frac{dh}{dy}\right\|_e\right\| > \text{EPSLN2}$ the boundary layer thickness is increased by adding an additional mesh point at the edge. (EPSLN2 need not be input for an incompressible case.)
EPSLN3	If, after a given solution of the elemen equation, $\left\|\frac{1}{\alpha_e}\ \left.\frac{d\alpha}{dy}\right\|_e\right\| > \text{EPSLN3}$, the boundary layer thickness is increased by adding an additional mesh point at the edge. (EPSLN3 need not be input for an incompressible or perfect gas case.)

Counters

Name	Description
MAXIT	Maximum number of iterations on the boundary layer solution at a given station. If the solution does not converge within MAXIT iterations, the program will proceed to the next station using the latest iterated values from this station. If MAXIT=0, only one calculation will be performed at each station. (Nominal value =1.)
NYI	Initial number of mesh intervals across the boundary layer (integer). Thus the initial number of mesh points will be NYI + 1.
NLPRNT	(Integer) Boundary layer profiles of u/u_e, h/h_e, ρ/ρ_e, ρv, ϵ, and T versus y and $\overline{y}$ are output every NLPRNT stations. These profiles are also output at the initial and final stations and at those x-values given in the array XLIM. After each XLIM-value is reached, the station print counter is reset to zero, and these profiles are not output again until NLPRNT stations have been computed (unless the next XLIM-value is reached first). (Nominal value = 50).
NSPRNT	(Integer) Boundary layer profiles of O/F, the species mass fractions, μ, and Pr versus $\overline{y}$ are output every NSPRNT stations for a hydrogen-oxygen equilibrium case. (NSPRNT should not be input for a perfect gas case.) For an equilibrium case NSPRNT, if input, should be an integer multiple of NLPRNT. If NSPRNT is not input, the profiles under the control of NSPRNT will be output at the initial, final, and XLIM stations only.
IYPR	(Integer) When profiles are output, the values at every IYPRth mesh point will be printed. In addition, properties at the wall and edge are always printed. (Nominal value =1; i.e. every mesh point is printed.)
IYEQ	(Integer) For a hydrogen-oxygen equilibrium case, equilibrium calculations are performed at the wall and every IYEQ mesh points thereafter. (Nominal value = 4.) Interpolation is then used to obtain the equilibrium properties at the remaining mesh points.

Tables

The remainder of the input in the DATA namelist consists of tables. In general, there will be three variable names associated with each table:

(1) an integer variable specifying the length of the table;

(2) an array of independent variable (argument) values in increasing order;

(3) an array of dependent variable values associated with the corresponding values in the argument array.

The input tables are described in functional groups below. Linear interpolation/extrapolation is used to obtain values of the dependent variables in the tables TWTAB vs XTABTW and SMDTAB vs XTABMD. An averaged parabolic interpolation method is used in the tables RWTAB vs XTABRW and PETAB vs XTABPE. No extrapolation is performed in these tables, so that the argument arrays must cover the entire range of possible arguments for a given case.

Stepsize Control Tables

Name	Description
LDXLIM	Number of entries in the arrays DXLIM and XLIM (≤ 50).
DXLIM XLIM	DXLIM (I) contains the normalized stepsize $\Delta x = \frac{\Delta \bar{x}}{L}$ to be used when the boundary layer solution reaches $\bar{x}/x_N$ = XLIM (I). The stepsize at the previous station is reduced if necessary to hit XLIM (I) exactly. A printout of the variable profiles across the boundary layer occurs at every point in the array XLIM. The last entry in XLIM (that is, XLIM (LDXLIM) must be greater than or equal to XMAX; otherwise the case will be terminated at XLIM (LDXLIM). The first entry, XLIM (1), must be greater than XINIT. (Note that DXI already specifies the initial stepsize.)
LSKTAB	Number of entries in the arrays SKTAB and XTABSK (≤ 50).

Name	Description
SKTAB XTABSK	SKTAB (I) contains the stepsize multiplication factor k_i to be used until $\bar{x}/x_N$ equals or exceeds XTABSK (I). The k_i are used as follows: each succeeding stepsize is calculated as k_i times its preceding stepsize. Thus the stepsize Δx can be steadily increased, decreased, or held constant over specified ranges using these arrays. Since the stepsize can be reset to an arbitrary value at any point along the boundary layer using DXLIM and XLIM, these stepsize control tables give the user considerable flexibility in controlling the boundary layer solution. The first entry in XTABSK must be greater than XINIT. The last entry, XTABSK (LSKTAB), must be greater than or equal to XMAX; otherwise the case will be terminated at XTABSK (LSKTAB).

Wall Tables

Name	Description
LTWTAB	Number of entries in the arrays TWTAB and XTABTW (≤ 100).
TWTAB XTABTW	Table of wall temperature T_w vs $\bar{x}/x_N$. TWTAB (I) is the value of T_w corresponding to the value of $\bar{x}/x_N$ in XTABTW (I). Values in XTABTW must be increasing order; however, at a discontinuity in T_w, the argument should be repeated once.
LMDTAB	Number of entries in the arrays SMDTAB and XTABMD (≤ 100).
SMDTAB XTABMD	Table of mass addition $\bar{\dot{m}}_w/\dot{m}_N$ vs $\bar{x}/x_N$. SMDTAB (I) is the value of $\bar{\dot{m}}_w/\dot{m}_N$ corresponding to the value of $\bar{x}/x_N$ in XTABMD (I). Values in XTABMD must be in increasing order; however, at a discontinuity in $\bar{\dot{m}}_w/\dot{m}_N$, the argument should be repeated once.

Geometry and Edge Tables

Name	Description
LRWTAB	Number of entries in the arrays RWTAB and XTABRW (≤ 500), if these are used to enter the wall contour table; OR, if the wall contour table is input in the TDKINP namelist, then LRWTAB must be the number of entries in the arrays YITAB and XITAB.
RWTAB XTABRW	Table of wall radius $\bar{r}_w/x_N$ vs $\bar{x}/x_N$. RWTAB (I) is the value of $\bar{r}_w/x_N$ corresponding to the value of $\bar{x}/x_N$ in XTABRW (I). Values in XTABRW must be in increasing order. If the wall contour table is input from TDK, these arrays should not be input.
LPETAB	Number of entries in the arrays PETAB and XTABPE (≤ 500) if these are used to enter the pressure table; OR, if the pressure table is input in the TDKINP namelist, then LPETAB must be the number of entries in the arrays PITAB and XITAB.
PETAB XTABPE	Table of $\bar{P}_e/P_N$ vs $\bar{x}/x_N$. PETAB (I) is the value of $\bar{P}_e/P_N$ corresponding to the value of $\bar{x}/x_N$ in XTABPE (I). Values in XTABPE must be in increasing order. If the pressure table is input from TDK, these arrays should not be input. If a pressure table is input, either in these arrays or in the TDKINP namelist, then the edge velocity table UETAB will be generated by the program and must not be input.
LUETAB	Number of entries in the array UETAB (≤ 500), if an edge velocity table is input. An edge velocity table may be input only for a perfect gas case.

Name	Description
UETAB XTABPE	Table of $\bar{u}_e/u_N$ vs $\bar{x}/x_N$. UETAB (I) is the value of $\bar{u}_e/u_N$ corresponding to the value of $\bar{x}/x_N$ in XTABPE (I). Values in XTABPE must be in increasing order. If a velocity table is input, then the pressure table PETAB will be generated by the program, and the pressure table must not be input, either in PETAB or in the TDKINP namelist. Note that XTABPE is the argument array for both PETAB and UETAB but that one and only one of the latter is input in a given case. The edge velocity table, whether input or generated from the pressure table PETAB, is used during initialization to generate a table of $\frac{du_e}{dx}$ vs x. Linear interpolation is performed in this latter table, and the edge velocity u_e is obtained at each station by integrating $\frac{du_e}{dx}$, rather than by interpolating directly in the table UETAB vs XTABPE.

Experimental Profiles

Experimental initial profiles for u, h, and α may be optionally input and will override the initial profiles normally calculated by the program. If experimental profiles are to be used at all, the velocity profile UPRØF vs YBYNU must be input. For a compressible case in which an experimental velocity profile is input, the enthalpy profile HPRØF vs YBYNH must also be input. For an incompressible case, the enthalpy profile should not be input. For a perfect gas case, the α-profile APRØF vs YBYNA should not be input; for an equilibrium case, an experimental α-profile may be input but is not required.

Averaged parabolic interpolation is used in all three experimental profile tables.

Name	Description
LUPRØF	Number of entries in the arrays UPRØF and YBYNU (≤ 50).

Name	Description
UPRØF YBYNU	Table of initial $\bar{u}/\bar{u}_e$ vs $\bar{y}/y_N$. UPROF (I) is the value of $\bar{u}/\bar{u}_e$ corresponding to the value of $\bar{y}/y_N$ in YBYNU (I). Values in YBYNU must be in increasing order.
LHPRØF	Number of entries in the arrays HPRØF and YBYNH (≤ 50).
HPRØF YBYNH	Table of initial $\bar{h}/\bar{h}_e$ vs $\bar{y}/y_N$. HPRØF (I) is the value of $\bar{h}/\bar{h}_e$ corresponding to the value of $\bar{y}/y_N$ in YBYNH (I). Values in YBYNH must be in increasing order.
LAPRØF	Number of entries in the arrays APRØF and YBYNA (≤ 50).
APRØF YBYNA	Table of initial α vs $\bar{y}/y_N$. APRØF (I) is the value of α corresponding to the value of $\bar{y}/y_N$ in YBYNA (I). Value in YBYNA must be in increasing order.

Replacement of a Table by a Constant Value

To replace a table by a constant value, enter the constant value in the first cell of the dependent variable array and make no entry for the length of that table or the argument array.

e.g. for a flat plate:

RWTAB (1) = constant ,

(Make no entry for LRWTAB or XTABRW.)

TDKINP NAMELIST

This group of data is entered only if INTDK = 1 in the preceding DATA namelist. Input follows the standard NAMELIST format. The first card of this group must contain $TDKINP starting in column 2. The data entries for the TDKINP namelist are punched out by the Two-Dimensional Kinetics Program (Reference 1). The last card of this group must contain $END starting in column 2.

If the TDKINP namelist is input for a case, then LRWTAB and LPETAB in the DATA namelist must be input as the length of the arrays YITAB, PITAB, and XITAB (all are the same length). In addition, the arrays RWTAB, XTABRW, PETAB, XTABPE, and UETAB in the DATA namelist must not be input.

The arrays in the TDKINP namelist, although punched out by TDK, are described below so that they may be edited by the user if desired.

Name	Description
YITAB PITAB XITAB	YITAB (I) and PITAB (I) are the values of $\bar{r}_w/x_N$ and $\bar{P}_e/P_N$ corresponding to the value of $\bar{x}/x_N$ in XITAB (I).
ZMTAB TITAB CPITAB VITAB RØITAB	These arrays, although punched out by TDK and contained in the TDKINP namelist, are not used by the program. They are read into a dummy storage area and later overlaid by other program arrays. Their values should be disregarded.

The TDK punched output does not go all the way back to the chamber. The offset option in TDK (IOFF, see Section 6.5.3.6 in Reference 1) should be used to allow room for points in the pressure and nozzle radius tables upstream of the first TDK output point.

THERMØ AND REACTANTS DATA FOR ØDE CALCULATIONS

The final group of input data is the THERMØ data and REACTANTS data for the One-Dimensional Equilibrium subroutines. This data is entered only if IDEAL = 0 in the DATA namelist, that is, only for a hydrogen-oxygen equilibrium case. The data cards in this group are fixed as to number, order, and content and should not be altered; they are listed below.

The THERMØ data contains thermodynamic data for the six chemical species considered in the hydrogen-oxygen system, namely H, H_2, H_2O, O OH, and O_2. The REACTANTS data contains information pertaining to the chemical reactants hydrogen and oxygen. The REACTANTS data must be terminated by a single blank data card.

```
THERMO DRUM
   300.000  1000.000  5000.000
H                 J 9/65H   100  000  000  0G   300.000  5000.000           1
 0.25000000E 01 0.              0.              0.              0.            2
 0.25471627E 05-0.46011763E 00 0.25000000E 01 0.              0.            3
 0.              0.            0.25471627E 05-0.46011762E 00                 4
H2                J 3/61H   20   00   00   0G   300.000  5000.000           1
 0.31001901E 01 0.51119464E-03 0.52644210E-07-0.34909973E-10 0.36945345E-14  2
-0.87738042E 03-0.19629421E 01 0.30574451E 01 0.26765200E-02-0.58099162E-05  3
 0.55210391E-08-0.18122739E-11-0.98890474E 03-0.22997056E 01                 4
H20               J 3/61H   20   100  000  0G   300.000  5000.000           1
 0.27167633E 01 0.29451374E-02-0.80224374E-06 0.10226682E-09-0.48472145E-14  2
-0.29905826E 05 0.66305671E 01 0.40701275E 01-0.11084499E-02 0.41521180E-05  3
-0.29637404E-08 0.80702103E-12-0.30279722E 05-0.32270046E 00                 4
O                 J 6/620   100  000  000  0G   300.000  5000.000           1
 0.25420596E 01-0.27550619E-04-0.31028033E-08 0.45510674E-11-0.43680515E-15  2
 0.29230803E 05 0.49203080E 01 0.29464287E 01-0.16381665E-02 0.24213216E-05  3
-0.16028432E-08 0.38906964E-12 0.29147644E 05 0.29639949E 01                 4
OH                J 3/66O   1H   100  000  0G   300.000  5000.000           1
 0.29106427E 01 0.95931650E-03-0.19441702E-06 0.13756646E-10 0.14224542E-15  2
 0.39353815E 04 0.54423445E 01 0.38375943E 01-0.10778858E-02 0.96830378E-06  3
 0.18713972E-09-0.22571094E-12 0.36412823E 04 0.49370009E 00                 4
O2                J 9/65O   20   00   00   0G   300.000  5000.000           1
 0.36219535E 01 0.73618264E-03-0.19652228E-06 0.36201558E-10-0.28945627E-14  2
-0.12019825E 04 0.36150960E 01 0.36255985E 01-0.18782184E-02 0.70554544E-05  3
-0.67635137E-08 0.21555993E-11-0.10475226E 04 0.43052778E 01                 4
END
REACTANTS
H 2.                                        100.     0.       G298.15  F
O 2.                                        100.0    0.0      G298.15  0
```

Blank Card

THERMO and REACTANTS Data for One-Dimensional Equilibrium Calculations

5. DESCRIPTION OF PROGRAM OUTPUT

The various features of the output from the Mass Addition Boundary Layer Program are described here. The details of the output format can be seen in the sample case output. Portions of the output are described in the order in which they appear in a case.

PRINTOUT OF PROGRAM INPUT

The combined input from the DATA and TDKINP namelists is printed at the beginning of a case. All single-cell input variables appear on the first page, each in the format

name = value.

Where no value was input, the nominal or default value is printed. These variables are printed in functional groups, under the following headings:

FLAGS AND OPTIONS
PROBLEM LIMITS AND INITIAL VALUES
REFERENCE QUANTITIES
INPUT NORMALIZATION FACTORS
EDGE QUANTITIES
CONSTANTS
CONVERGENCE AND EDGE CRITERIA
COUNTERS

Tabular input data is printed on subsequent pages of the input printout. For each table, the table length is printed, followed by the dependent variable array and the independent variable array in adjacent columns. The tables are grouped under the following headings:

STEPSIZE CONTROL TABLES
WALL TABLES
GEOMETRY AND EDGE TABLES

(If the wall contour and pressure tables were entered in the TDKINP namelist, they will appear here as RWTAB, XTABRW, PETAB, and XTABPE.)

EXPERIMENTAL PROFILES

(These pages will appear only if experimental profiles were input.)

ONE-DIMENSIONAL EQUILIBRIUM DATA

Data for the reactants hydrogen and oxygen are printed if this is an equilibrium case, and the chemical species considered for the hydrogen-oxygen system (those in the THERMØ data) are listed.

EDGE VELOCITY TABLE

The edge velocity table (u_e vs x), whether input or generated from the input pressure table, is printed before generating the table of $\frac{\partial u_e}{\partial x}$ vs x. The velocities are printed in order from left to right under the heading EDGE VELOCITY; the corresponding x's are printed under the heading AXIAL DISTANCE. The velocity as printed is normalized by u_r; the axial distance is normalized by L. (Recall that the edge velocity u_e in the boundary layer solution is obtained by integrating $\frac{\partial u_e}{\partial x}$ rather than by interpolating in the velocity table.)

G-FUNCTION OUTPUT

If a stretching function G has been specified by entering values for the input variables SN3 and GPØ, data pertaining to this function will appear next in the output. For each initial boundary layer mesh point and for 30 additional mesh points beyond the edge (in case points are later added during the boundary layer solution), the following quantities are printed in adjacent columns:

$y = \frac{\bar{y}}{L\zeta}$, under the heading YTIL;

$y = G(\bar{y})$, under the heading Y = G;

$G'(\bar{y})$, under the heading GP;

$G''(\bar{y})$, under the heading GPP.

BOUNDARY LAYER PROFILES

As explained in the Description of Program Input, profiles of various properties across the boundary layer are printed on a schedule governed by the input quantities NLPRNT and NSPRNT and at those axial distances in the input array XLIM. Starting with the wall point, every IYPRth point across the boundary layer will appear in the profiles. The edge point is always printed as well.

For every station at which the profiles are output, the following boundary layer quantities are printed above the profiles:

STATION, X, S, DS, RW, THETAW, ZETA, ZETAP;
Edge and wall conditions UE, TE, HE, PE, ME, RHOE, MUE, TW, MDØTW;
Profile parameters DELTA*, THETA, TAUW, QW, CF, ST.

These quantities also appear in the summary table at the end of a case and are explained in d ¹ in the next section.

Profiles printed under the control of NLPRNT appear first at a given station and are designated as Group I profiles. These profiles are printed in columns adjacent to one another; hence each row of output represents a single mesh point. The table below describes the Group I profile quantities printed for a given mesh point. Note that the temperature T is solved directly only at every IYEQth mesh point for an equilibrium case; temperatures at the intermediate mesh points are obtained by interpolation using the known points.

Name	Description	Units
NØ.	Mesh point # (wall = 1).	———
YBAR	$\bar{y}$, physical normal coordinate.	ft.
Y	y, normalized coordinate.	———
U/UE	$\bar{u}/\bar{u}_e$	———
H/HE	$\bar{h}/\bar{h}_e$	———
RØ/RØE	$\bar{\rho}/\bar{\rho}_e$	———
RØV	$\rho v = \dfrac{\overline{\rho v} + \overline{\rho}'\overline{v}'}{\rho_r u_r \zeta}$	———
EPS	Eddy viscosity (normalized) $\epsilon = \bar{\epsilon}\rho_r/\mu_r$	———
T	Temperature	°R

Profiles printed under the control of NSPRNT will follow the Group I profiles and are designated as Group II profiles. These profiles will appear only for an equilibrium case. Like the Group I profiles, they are printed in columns adjacent to one another, so that each row of output represents a single mesh point. The table below describes the Group II profile quantities printed for a given mesh point.

Name	Description	Units
NØ.	Mesh point #.	———
YBAR	$\bar{y}$, physical normal coordinate.	ft.
Ø/F	Oxidant/fuel ratio.	———
C(H)	Mass fraction of H.	———
C(H2)	Mass fraction of H2.	———
C(H2Ø)	Mass fraction of H2Ø.	———
C(Ø)	Mass fraction of Ø.	———
C(ØH)	Mass fraction of OH.	———
C(Ø2)	Mass fraction of Ø2.	———
MU	Normalized viscosity $\mu = \bar{\mu}/\mu_T$	———
PR	Prandtl number	———

The species mass fractions, viscosity, and Prandtl number, like temperature, are solved directly only at every IYEQth mesh point. Viscosity and Prandtl number at the intermediate mesh points are obtained by interpolation using the known points. Values of zero are printed for the species mass fractions at the intermediate points; species mass fractions are not interpolated unless Lewis number and turbulent Lewis number are not unity, because the terms in which they appear in the boundary layer equations drop out when Le = 1 and Le_T = 1. Should points be added at the edge of the boundary layer during the solution, the species mass fractions at the added points, although non-zero, are meaningless, except at those points where they are solved directly (every IYEQth point, plus the edge point.)

SUMMARY TABLE

A summary print of important boundary layer quantities at each station appears at the end of a case. Each page of the summary table contains data for thirteen stations. At the top of each page are three lines indicating the names and format of the variables printed for each station. The following table explains the quantities printed in the summary table:

Name	Description	Units
STATIØN	Station number.	———
X	Normalized axial distance $x = \bar{x}/L$.	———
S	Normalized wetted length $s = \bar{s}/L$.	———
RW	Normalized wall radius, $r_w = \bar{r}_w/L$	———
THETAW	Wall angle. $\theta_w = \tan^{-1} \frac{dr_w}{dx}$	radians
DS	Δs, normalized integration stepsize.	
UE	$\bar{u}_e$, edge velocity.	ft/sec
TE	T_e, edge temperature	°R
HE	$\bar{h}_e$, edge enthalpy.	ft^2/sec^2
ME	Mach number at edge.	———
PE	$\bar{P}_e$, edge pressure.	lb_f/ft^2
RHØE	$\bar{\rho}_e$, density at edge.	$lb_f sec^2/ft^4$
MUE	$\bar{\mu}_e$, viscosity at edge.	$lb_f sec/ft^2$
MDOTW	Mass addition at wall. $\bar{\dot{m}}_w = \frac{1}{2}\left(\frac{\bar{\dot{m}}_{w_m}}{\zeta_m} + \frac{\bar{\dot{m}}_{w_{m+1}}}{\zeta_{m+1}}\right)\zeta_{m+1/2}$	$lb_f sec/ft^3$

Name	Description	Units
TW	T_w, wall temperature.	°R
CF	C_f, local shear stress coefficient. $C_f = \tau_w / \frac{1}{2} \bar{\rho}_e \bar{u}_e^2$	———
TAUW	τ_w, wall shear stress.	lb_f/ft^2
ST	Stanton number. $St = -q_w / \bar{\rho}_e \bar{u}_e (H_e - H_w)$	———
QW	$-q_w$, heat transfer rate.	$ft\text{-}lb_f/ft^2sec$
SUMQW	$-(2\pi)^j \int_{\bar{s}_{init}}^{\bar{s}} (\bar{r}_w)^j q_w d\bar{s}$	$ft\text{-}lb_f/sec$
DELTA*	δ^*, displacement thickness.	ft
THETA	θ, momentum thickness.	ft
ADDMAS	$\int_{\bar{s}_{init}}^{\bar{s}} \dot{m}_w \zeta r_w^j ds$, part of the mass addition correction to the displacement thickness.	———
ZETA	Value of the boundary layer normalization function ζ.	———
ZETAP	Value of ζ', the derivative of the boundary layer normalization function.	———
DUEDS	$\frac{d(\bar{u}_e/u_1)}{d(\bar{s}/L)}$, normalized edge velocity derivative.	———
RWPR	Displacement thickness corrected nozzle radius, normalized by corrected throat radius.	———
XPR	Axial distance normalized by δ^* corrected throat radius.	———

AFTER THE SUMMARY TABLE

Following the summary table printout the program prints out the displacement thickness corrected throat radius and the thrust loss (in lbs) due to boundary layer effects.

ERROR MESSAGES AND DIAGNOSTICS

Following are the error messages and diagnostics which may be output from the Mass Addition Boundary Layer Program.

(1) POINT WAS ADDED TO BOUNDARY LAYER IN SUBROUTINE {MOMNTM / ENERGY / ELEMTS}
AT STATION _____ AND ITERATION _____.

This is a diagnostic message rather than an error message. It indicates that the edge criterion for velocity (subroutine MOMNTM), enthalpy (subroutine ENERGY), or mass fraction of hydrogen (subroutine ELEMTS) has not been satisfied, resulting in the addition of a mesh point at the edge of the boundary layer. The criteria for adding points are given in the Description of Program Input under the input variables EPSLN1, EPSLN2, and EPSLN3.

(2) EXIT CALLED FROM SUBROUTINE {MOMNTM / ENERGY / ELEMTS} AT STATION _____
AND ITERATION _____.

This fatal error message results (a) if six mesh points must be added to the boundary layer in a single iteration in the subroutine indicated, or (b) if another mesh point must be added when the maximum possible number of mesh points in the boundary layer (250) has been reached.

(3) XNTERP OUT OF RANGE . . . X = _____, X(1) = _____, X(N) = _____
Y(1) = _____, Y(N) = _____

This message is printed by the parabolic interpolation routine when an argument, given by X, exceeds the bounds of the independent variable array, given by X(1) and X(N). The dependent variable values corresponding to X(1) and X(N) are given by Y(1) and Y(N). Recall that averaged parabolic interpolation is used in the tables RWTAB vs XTABRW, PETAB vs XTABPE, and in the experimental profile tables UPRØF vs YBYNU, HPRØF vs YBYNH, and APRØF vs YBYNA.

6. OPERATING PROCEDURES

This section contains information pertaining to the hardware and software requirements and the execution of the Mass Addition Boundary Layer Program.

CORE REQUIREMENTS

The UNIVAC 1108 version of the program requires overlay; with the overlay structure currently implemented using the Memory Allocation Processor and with the current program dimensions (250 points allowed in the boundary layer), the program requires 47800 words of core.

FORTRAN LOGICAL UNITS AND I/Ø DEVICES

The Mass Addition Boundary Layer Program accesses the following I/Ø devices through their corresponding FORTRAN logical units:

Logical Unit	I/O Device	Function
5	Card reader	Input
6	Printer	Output
16	User PCF	Scratch
17	User scratch	Temporary summary table storage
29	Last fifth of user drum	Temporary THERMØ data storage

If any of these logical unit assignments are non-standard at a particular UNIVAC 1108 installation, appropriate changes to the system NTAB$ routine will be necessary.

SPECIAL SYSTEM ROUTINES

A system subroutine ERRØRX is called at the beginning of subroutine EXECUT to allow the summary table to be printed before case termination in the event of a transfer to the system error exit routine MERR$. Subroutine ERRØRX may not be available at other installations; if not, the call to ERRØRX may be removed, with the result that a negative argument tor the square root function, for example, will abort the run without a summary table print. This could be remedied by assigning logical unit 17 to a save tape and processing the tape independently in a manner similar to that in subroutine SUMTAB.

Execution

The Mass Addition Boundary Layer Program may be executed from the absolute element on the program tape via the control card

```
7
8 XQT TBLABS
```

The program may be executed from the relocatable elements on the program tape by referencing the processed MAP element via the control card

```
7
8 XQT MAPTBL
```

The input data deck which follows the XQT card will have the following general form:

```
Case title card
b$DATA
    DATA Namelist          } Always present
b$END
b$TDKINP
    TDKINP Namelist        } Present only if INTDK = 1 in DATA namelist
b$END
THERMØ DRUM
    Species thermodynamic
    data
END                        } Present only if IDEAL = 0 in DATA namelist
REACTANTS
    Reactants data
Blank data card
```

A perfect gas case may be run without overlay provided a dummy version of subroutine HØØDE is used to override the version of HØØDE on the program tape, as follows:

```
SUBROUTINE HØØDE (J)
RETURN
END
```

The program will then be loaded and executed, minus all of the One-Dimensional Equilibrium subroutines, via the control card

```
7
8 XQT TFCBL
```

7. SAMPLE CASES

Two sample cases are presented in order to facilitate program check-out. One case is a perfect gas solution while the other is the beginning of an H_2-O_2 equilibrium solution. Both cases are rocket engine flows and make use of the same TDK generated nozzle shape and pressure distribution. The input supplied with both cases has been set up to allow a complete solution to be obtained out to a normalized distance, x, of 21.39, however, for check-out purposes the perfect gas solution is terminated at XMAX = .052 and the equilibrium case is terminated after the first twenty steps. The length of the sample cases was restricted so that the program could be checked out without large expenditures of computer time and money.

INPUT

The input required to run the sample cases is contained in the fourth file of the tape containing the program itself. The output part of this section contains a copy of the input for each case as printed out by the program, so that the accuracy of the data punched from the tape can be verified.

OUTPUT

A sufficient sample of the output from the perfect gas case and essentially the complete output of the short equilibrium test case have been reproduced and are presented below. Both cases use the same TDKINP Namelist Data, thus to avoid repetition the PETAB and RWTAB tables are presented only once, with the perfect gas sample output.

PERFECT GAS SAMPLE CASE

PERFECT GAS SAMPLE CASE

FLAGS AND OPTIONS

```
IDEAL =  1      (=1 FOR PERFECT GAS, =0 FOR HYDROGEN-OXYGEN EQUILIBRIUM)
LAMP  =  0      (=1 FOR LAMINAR FLOW, =0 FOR TURBULENT)
INCOMP=  0      (=1 FOR INCOMPRESSIBLE FLOW, =0 FOR COMPRESSIBLE)
J2D   =  1      (=1 FOR AXISYMMETRIC GEOMETRY, =0 FOR TWO-DIMENSIONAL)
INTDK =  1      (=1 IF INPUT TABLES COME FROM TDK OUTPUT, =0 OTHERWISE)
```

PROBLEM LIMITS AND INITIAL VALUES

```
SINIT =  0.0000000      XINIT = -3.5516000+00    XMAX  =  5.2000000-02    DXI   =  6.5499999-05
DELTAI=  6.9999999-05   ZETAPI=  0.0000000
```

REFERENCE QUANTITIES

```
LREF  =  3.0502500-01   UREF  =  1.0000000+03    RHOREF=  3.0000000-03    SMUREF=  5.0000000-07
```

INPUT NORMALIZATION FACTORS

```
YA    =  3.0502500-01   YN    =  1.0000000+00    UEN   =  1.0000000+00    PEN   =  4.4596800+05    SMDN  =  4.4760000+00
```

EDGE QUANTITIES

```
YEDGE =  0.0000000      PEDGE =  1.0000000+00    TEDGE =  6.5899999+03    AMEDGE=  1.3717000-01
```

CONSTANTS

```
AMTRNS=  0.0000000      PRI   =  5.9999999-01    GAMMA =  1.1900000+00    FMOLWT=  1.4500000+01    PLAW  =  1.0000000+00
PAMB  =  0.0000000      GPO   =  1.0000000+03    SN3   =  4.0000001+00    XSTAR =  0.0000000       AMWALL= -9.9990000+03
REK   =  0.0000000      RHOEK =  0.0000000
```

CONVERGENCE AND EDGE CRITERIA

```
CONVRG=  4.9999999-03   EPSLN1=  3.0000000-02    EPSLN2=  3.0000000-02    EPSLN3=  3.0000000-02
```

COUNTERS

```
MAXIT =  1              MYI   =  12              NLPRNT=  20              NSPRNT=9999              IYPR  =  3
IYE   =  4
```

STEPSIZE CONTROL TABLES

LDXLIM= 10

DXLIM	XLIM
2,7300000-02	-3,3974000+00
2,5000000-02	-1,9120000+00
1,5000000-02	-5,0000000-01
2,0000000-03	-5,0000000-02
9,9999999-05	0,0000000
2,0000000-03	2,0000000-03
2,0000000-02	5,2000000-02
9,9999999-05	1,9120000+00
2,0000000-01	3,0100000+00
2.0000000-01	2,2000000+01

LSKTAB= 6

SKTAB	XTABSK
1,1500000+00	-3,3974000+00
1,0500000+00	-2,8624000+00
1,0000000+00	5,2000000-02
1,0100000+00	1,9120000+00
1,1500000+00	3,0100000+00
1,0000000+00	2,2000000+01

WALL TABLES

LTWTAB= 12

TWTAB	XTABTW
1.9000000+03	-3.5516000+00
1.9000000+03	-1.9120000+00
1.7000000+03	-1.3660000+00
1.7000000+03	0.0000000
1.9000000+03	0.0000000
1.9000000+03	1.9120000+00
1.4400000+03	1.9120000+00
1.2800000+03	3.0050000+00
1.0800000+03	4.1000000+00
1.0000000+03	6.8300000+00
1.1000000+03	8.4700000+00
1.6200000+03	2.1390000+01

LMDTAB= 27

SMDTAB	XTABMD
6.6000000-03	-3.5516000+00
6.6000000-03	-3.4150000+00
6.6000000-03	-3.1420000+00
6.6000000-03	-2.8690000+00
7.3000000-03	-2.5950000+00
4.8000000-03	-2.3220000+00
4.8000000-03	-2.0490000+00
5.9000000-03	-1.7760000+00
4.8000000-03	-1.5030000+00
6.6999999-03	-1.2290000+00
8.9999999-03	-9.9699999-01
1.3600000-02	-8.3300000-01
1.4800000-02	-6.9700000-01
2.2600000-02	-5.5999999-01
2.7600000-02	-4.2300000-01
3.9700000-02	-2.8700000-01
3.6600000-02	0.0000000
7.2200000-03	4.1000000-02
5.1299999-03	1.3700000-01
9.5999999-03	2.6000000-01
4.8800000-03	3.5500000-01
2.2500000-03	5.4600000-01
2.3300000-03	8.0999999-01
1.5700000-04	1.1340000+00
7.9999999-04	1.3850000+00
0.0000000	1.8300000+00
0.0000000	2.2000000+01

GEOMETRY AND EDGE TABLES

LRWTAB= 133

RWTAB	XTABRW
1,7227900+00	-3,5516000+00
1,7227900+00	-3,0050000+00
1,7227900+00	-2,4590000+00
1,7227900+00	-1,8719200+00
1,7216200+00	-1,8086000+00
1,7169900+00	-1,7306700+00
1,7087900+00	-1,6527400+00
1,6969700+00	-1,5748100+00
1,6814600+00	-1,4968800+00
1,6621600+00	-1,4189500+00
1,6389300+00	-1,3410200+00
1,6116000+00	-1,2630800+00
1,5799600+00	-1,1851500+00
1,5437400+00	-1,1072200+00
1,5026200+00	-1,0292900+00
1,4561700+00	-9,5136300-01
1,4038700+00	-8,7343200-01
1,3450300+00	-7,9550200-01
1,2788800+00	-7,1757100-01
1,2142400+00	-6,3964099-01
1,1607100+00	-5,6170999-01
1,1165900+00	-4,8378000-01
1,0806100+00	-4,0584900-01
1,0518900+00	-3,2791900-01
1,0298400+00	-2,4998800-01
1,0132400+00	-1,7205700-01
1,0033600+00	-8,4385799-02
1,0006000+00	-3,5765000-02
1,0000100+00	-3,6326100-03
1,0000000+00	0,0000000
1,0000100+00	9,4799399-04
1,0000400+00	1,9287500-03
1,0000900+00	2,9384900-03
1,0001600+00	3,9702500-03
1,0002500+00	5,0332399-03
1,0003800+00	6,1212099-03
1,0005300+00	7,2329099-03
1,0007100+00	8,3675799-03
1,0009200+00	9,5248800-03
1,0011600+00	1,0704700-02
1,0014400+00	1,1906700-02
1,0017500+00	1,3130600-02
1,0021100+00	1,4376500-02
1,0025100+00	1,5644500-02
1,0029600+00	1,6934500-02
1,0034500+00	1,8246600-02
1,0039900+00	1,9581000-02
1,0046000+00	2,0937800-02
1,0052600+00	2,2317100-02
1,0059800+00	2,3719100-02
1,0067800+00	2,5144000-02

LPETAB= 133

PETAB	XTABPE
9,9699999-01	-3,5516000+00
9,9640000-01	-3,0050000+00
9,8999999-01	-2,4590000+00
9,7678499-01	-1,8719200+00
9,7610800-01	-1,8086000+00
9,7382299-01	-1,7306700+00
9,7031199-01	-1,6527400+00
9,7455300-01	-1,5748100+00
9,7350900-01	-1,4968800+00
9,7213200-01	-1,4189500+00
9,7034900-01	-1,3410200+00
9,6808700-01	-1,2630800+00
9,6510600-01	-1,1851500+00
9,6127699-01	-1,1072200+00
9,5623200-01	-1,0292900+00
9,4943700-01	-9,5136300-01
9,3999799-01	-8,7343200-01
9,2631000-01	-7,9550200-01
9,0577199-01	-7,1757100-01
8,8029899-01	-6,3964099-01
8,5111300-01	-5,6170999-01
8,1815000-01	-4,8378000-01
7,8147899-01	-4,0584900-01
7,4131100-01	-3,2791900-01
6,9800500-01	-2,4998800-01
6,4911400-01	-1,7210700-01
5,9798899-01	-8,4385799-02
5,3882699-01	-3,5765000-02
4,4988800-01	-3,6326100-03
4,4256900-01	0,0000000
4,2214800-01	9,4799399-04
4,0343900-01	1,9287500-03
3,8428700-01	2,9384900-03
3,6600700-01	3,9702500-03
3,4777000-01	5,0332399-03
3,3044900-01	6,1212099-03
3,1396200-01	7,2329099-03
2,9711400-01	8,3675799-03
2,8108700-01	9,5248800-03
2,6546500-01	1,0704700-02
2,5024200-01	1,1906700-02
2,3541900-01	1,3130600-02
2,2098000-01	1,4376500-02
2,0693400-01	1,5644500-02
1,9327800-01	1,6934500-02
1,8001500-01	1,8246600-02
1,6714600-01	1,9581000-02
1,5467400-01	2,0937800-02
1,4260600-01	2,2317100-02
1,3094500-01	2,3719100-02
1,1969900-01	2,5144000-02

RWTAB	XTABRW	PETAB	XTABPE
1.0076600+00	2.6600700-02	1.1233900-01	2.6600700-02
1.0085500+00	2.8056200-02	1.1248900-01	2.8056200-02
1.0094300+00	2.9491400-02	1.1266900-01	2.9491400-02
1.0103100+00	3.0930000-02	1.1282900-01	3.0930000-02
1.0111900+00	3.2369700-02	1.1299800-01	3.2369700-02
1.0120700+00	3.3804800-02	1.1318500-01	3.3804800-02
1.0129500+00	3.5235500-02	1.1337600-01	3.5235500-02
1.0138300+00	3.6662199-02	1.1356500-01	3.6662199-02
1.0147000+00	3.8087600-02	1.1375000-01	3.8087600-02
1.0161000+00	4.0369500-02	1.1224700-01	4.0369500-02
1.0181500+00	4.3714999-02	1.1115500-01	4.3714999-02
1.0212200+00	4.8732300-02	1.1010700-01	4.8732300-02
1.0259900+00	5.5864200-02	1.1101600-01	5.5864200-02
1.0324400+00	6.7034899-02	1.0960300-01	6.7034899-02
1.0424600+00	8.3387899-02	1.0909800-01	8.3387899-02
1.0574800+00	1.0791100-01	1.0758300-01	1.0791100-01
1.0795900+00	1.4398700-01	1.0647300-01	1.4398700-01
1.1123300+00	1.9742100-01	1.0409100-01	1.9742100-01
1.1565100+00	2.6952000-01	1.0110100-01	2.6952000-01
1.1997900+00	3.4015400-01	9.8118099-02	3.4015400-01
1.2424400+00	4.0974900-01	9.4811000-02	4.0974900-01
1.2842500+00	4.7796800-01	9.2007499-02	4.7796800-01
1.3255800+00	5.4538000-01	8.9221799-02	5.4538000-01
1.3672100+00	6.1329900-01	8.5580000-02	6.1329900-01
1.4087100+00	6.8099000-01	8.2381399-02	6.8099000-01
1.4498900+00	7.4817199-01	7.9349699-02	7.4817199-01
1.4909200+00	8.1511900-01	7.6398999-02	8.1511900-01
1.5316500+00	8.8160100-01	7.3605799-02	8.8160100-01
1.5741500+00	9.5099799-01	7.0397099-02	9.5099799-01
1.6162600+00	1.0198100+00	6.7442600-02	1.0198100+00
1.6593100+00	1.0901700+00	6.4403799-02	1.0901700+00
1.7026100+00	1.1609400+00	6.1452899-02	1.1609400+00
1.7467300+00	1.2330100+00	5.8513399-02	1.2330100+00
1.7913800+00	1.3058800+00	5.5601100-02	1.3058800+00
1.8369800+00	1.3802000+00	5.2788899-02	1.3802000+00
1.8830300+00	1.4551100+00	4.9987800-02	1.4551100+00
1.9302400+00	1.5317500+00	4.7386800-02	1.5317500+00
1.9771500+00	1.6078400+00	4.5128900-02	1.6078400+00
2.0249100+00	1.6854200+00	4.2997800-02	1.6854200+00
2.0815000+00	1.7776200+00	4.0290400-02	1.7776200+00
2.1294800+00	1.8562900+00	3.8977200-02	1.8562900+00
2.1808100+00	1.9411100+00	3.7238900-02	1.9411100+00
2.2316800+00	2.0259700+00	3.6093599-02	2.0259700+00
2.2966500+00	2.1357400+00	3.3635600-02	2.1357400+00
2.3368000+00	2.2042800+00	3.3157100-02	2.2042800+00
2.3973300+00	2.3088100+00	3.1508300-02	2.3088100+00
2.4481200+00	2.3974600+00	3.0393000-02	2.3974600+00
2.5060700+00	2.4998800+00	2.9193600-02	2.4998800+00
2.5724000+00	2.6185900+00	2.7723900-02	2.6185900+00
2.7274800+00	2.9030000+00	2.4636200-02	2.9030000+00
2.8517100+00	3.1379500+00	2.2997100-02	3.1379500+00
3.0073400+00	3.4414600+00	2.0502400-02	3.4414600+00
3.1599300+00	3.7494800+00	1.8437200-02	3.7494800+00
3.3388400+00	4.1242000+00	1.6650800-02	4.1242000+00

RWTAB	XTABRW	PETAB	XTABPE
3,5185000+00	4,5155700+00	1,4935400-02	4,5155700+00
3,7300900+00	4,9961800+00	1,3074100-02	4,9961800+00
3,9521000+00	5,5241100+00	1,1593700-02	5,5241100+00
4,2017700+00	6,1488200+00	1,0110600-02	6,1488200+00
4,4608000+00	6,8346800+00	8,8745300-03	6,8346800+00
4,7532200+00	7,6593299+00	7,6111699-03	7,6593299+00
[illegible] 00	8,5883500+00	6,4753799-03	8,5883500+00
2201100+00	9,0982499+00	5,9878600-03	9,0982499+00
3833400+00	9,6414500+00	5,6111900-03	9,6414500+00
6761999+00	1,0282400+01	5,1289599-03	1,0282400+01
7631300+00	1,0997400+01	4,6366300-03	1,0997400+01
7427900+00	1,1688000+01	4,2806099-03	1,1688000+01
6,1183200+00	1,2395900+01	3,9754200-03	1,2395900+01
6,3021900+00	1,3175100+01	3,6594600-03	1,3175100+01
[illegible] 2000+00	1,4009500+01	3,3569700-03	1,4009500+01
[illegible] 1900+00	1,4912500+01	3,0894400-03	1,4912500+01
6,8643300+00	1,5819100+01	2,8362500-03	1,5819100+01
6,9607100+00	1,6315400+01	2,7175100-03	1,6315400+01
7,0526600+00	1,6802800+01	2,6197000-03	1,6802800+01
7,1428700+00	1,7295700+01	2,5339800-03	1,7295700+01
7,2301000+00	1,7787800+01	2,4595500-03	1,7787800+01
7,3191600+00	1,8307900+01	2,3853499-03	1,8307900+01
7,4051300+00	1,8829400+01	2,3214700-03	1,8829400+01
7,4933399+00	1,9387300+01	2,2548600-03	1,9387300+01
7,5782199+00	1,9949500+01	2,1976200-03	1,9949500+01
7,6569699+00	2,0497000+01	2,1541300-03	2,0497000+01
7,7335100+00	2,1058000+01	2,1150900-03	2,1058000+01
7,7769600+00	2,1390800+01	2,0733500-03	2,1390800+01

VELOCITY TABLE GENERATED

EDGE VELOCITY

.388458-00	.403674-00	.673692-00	.103003+01	.104448+01	.105069+01	.104185+01	.107822+01
.110037+01	.112893+01	.116494+01	.120972+01	.126517+01	.133388+01	.141967+01	.152817+01
.166816+01	.185430+01	.210658+01	.238826+01	.268196+01	.298784+01	.330561+01	.363458+01
.397382+01	.434421+01	.472335+01	.515862+01	.582400+01	.587742+01	.603420+01	.617983+01
.633122+01	.647826+01	.662772+01	.677277+01	.691724+01	.706138+01	.720545+01	.734978+01
.749458+01	.764007+01	.778648+01	.793407+01	.808305+01	.823365+01	.838614+01	.854079+01
.869786+01	.885768+01	.902059+01	.918268+01	.913027+01	.912748+01	.912500+01	.912238+01
.911949+01	.911654+01	.911362+01	.911077+01	.913403+01	.915106+01	.916750+01	.915320+01
.917545+01	.918343+01	.920753+01	.922533+01	.926393+01	.931323+01	.936337+01	.942018+01
.946934+01	.951922+01	.958602+01	.964629+01	.970489+01	.976342+01	.982026+01	.988741+01
.995113+01	.100187+02	.100865+02	.101563+02	.102280+02	.102998+02	.103739+02	.104455+02
.105100+02	.105730+02	.106563+02	.106982+02	.107552+02	.107939+02	.108799+02	.108972+02
.109582+02	.110008+02	.110479+02	.111076+02	.112410+02	.113361+02	.114407+02	.115519+02
.116560+02	.117641+02	.118927+02	.120053+02	.121298+02	.122447+02	.123756+02	.125086+02
.125713+02	.126225+02	.126922+02	.127687+02	.128282+02	.128823+02	.129418+02	.130029+02
.130604+02	.131187+02	.131474+02	.131718+02	.131939+02	.132134+02	.132335+02	.132511+02
.132699+02	.132864+02	.132991+02	.133108+02	.133234+02			

AXIAL DISTANCE

-.355160+01	-.300500+01	-.245900+01	-.187192+01	-.180860+01	-.173067+01	-.165274+01	-.157481+01
-.149688+01	-.141895+01	-.134102+01	-.126308+01	-.118515+01	-.110722+01	-.102929+01	-.951363-00
-.873432-00	-.795502-00	-.717571-00	-.639641-00	-.561710-00	-.483780-00	-.405849-00	-.327919-00
-.249988-00	-.167187-00	-.843858-01	-.367650-01	-.363261-02	.000000	.947994-03	.192875-02
.293849-02	.397025-02	.503324-02	.612121-02	.723291-02	.836758-02	.952488-02	.107047-01
.119067-01	.131306-01	.143765-01	.156445-01	.169345-01	.182466-01	.195810-01	.209378-01
.223171-01	.237191-01	.251440-01	.266007-01	.280562-01	.294914-01	.309300-01	.323697-01
.338348-01	.352355-01	.366622-01	.380876-01	.403695-01	.437150-01	.487323-01	.558642-01
.670349-01	.833879-01	.107911+00	.143987-00	.197421-00	.269520-00	.340154-00	.409749-00
.477966-00	.545370-00	.613299-00	.680990-00	.748172-00	.815119-00	.881601-00	.950998-00
.101981+01	.109017+01	.116094+01	.123301+01	.130588+01	.138020+01	.145511+01	.153175+01
.160784+01	.168542+01	.177762+01	.185629+01	.194111+01	.202597+01	.213574+01	.220428+01
.230881+01	.239746+01	.249988+01	.261859+01	.290300+01	.313795+01	.344146+01	.374948+01
.412420+01	.451557+01	.499618+01	.552411+01	.614882+01	.683468+01	.765933+01	.858835+01
.969825+01	.964145+01	.102824+02	.109974+02	.116880+02	.123959+02	.131751+02	.140095+02
.149125+02	.158191+02	.163154+02	.168028+02	.172957+02	.177878+02	.183079+02	.188294+02
.193873+02	.199495+02	.204970+02	.210580+02	.213908+02			

PERFECT GAS SAMPLE CASE

STATION	X	S	DS	RW	THETAW	ZETA	ZETAP
0	-3.5516000E+00	1.0000000	6.5499939E-05	1.7227900E+00	0.0000000	1.9124115E-04	4.6821737E-02

EDGE AND WALL CONDITIONS

UE	= .7954580E+03	ME	= .7107059E-01	DELTA*	= .1909092E-04
TE	= .6586839E+04	RHOE	= .1968569E-01	THETA	= .1745367E-04
HE	= .1414628E+09	MUE	= .1788395E-05	TAUW	= .5118337E+01
PE	= .4446301E+06	TW	= .1900000E+04	QW	= .2333822E+07
		MDOTW	= .0000000		

PROFILE PARAMETERS

DELTA*	= .1909092E-04	CF	= .3830303E-02
THETA	= .1745367E-04	ST	= .3194418E-02
TAUW	= .5118337E+01		
QW	= .2333822E+07		

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
1	0.0000000	-0.0000000	0.0000000	2.8445397E-01	3.4467575E+00	5.1491078E+01	0.0000000	1900.0
4	2.5242056E-09	2.7736664E-02	4.0066763E-05	2.8848249E-01	3.4664147E+00	5.1491044E+01	1.0032233E-15	1900.2
7	7.6097915E-09	5.5473328E-02	1.2079036E-04	2.8853998E-01	3.4657242E+00	5.1491116E+01	3.6111161E-14	1900.6
10	1.6587447E-08	8.3209991E-02	2.6329286E-04	2.8864144E-01	3.4645060E+00	5.1491244E+01	5.9131976E-13	1901.2
13	3.1069575E-08	1.1094668E-01	4.9316794E-04	2.8880511E-01	3.4625425E+00	5.1491451E+01	6.1138018E-12	1902.3
16	5.2952158E-08	1.3868332E-01	8.4051058E-04	2.8905243E-01	3.4595799E+00	5.1491764E+01	4.6160644E-11	1903.9
19	8.4418321E-08	1.6641998E-01	1.3399736E-03	2.8940807E-01	3.4553286E+00	5.1492214E+01	2.7585316E-10	1906.3
22	1.2794369E-07	1.9415645E-01	2.0308525E-03	2.8989999E-01	3.4494653E+00	5.1492836E+01	1.3726764E-09	1909.5
25	1.8630408E-07	2.2189331E-01	2.9572082E-03	2.9055957E-01	3.4416349E+00	5.1493669E+01	5.8988885E-09	1913.9
28	2.6258616E-07	2.4962997E-01	4.1680350E-03	2.9142171E-01	3.4314533E+00	5.1494759E+01	2.2334993E-08	1919.5
31	3.6020177E-07	2.7736664E-01	5.7174893E-03	2.9252496E-01	3.4185117E+00	5.1496153E+01	7.6318925E-08	1926.8
34	4.8290676E-07	3.0510330E-01	7.6651879E-03	2.9391176E-01	3.4023817E+00	5.1497906E+01	2.3840991E-07	1935.9
37	6.3482523E-07	3.3283997E-01	1.0076593E-02	2.9562872E-01	3.3826213E+00	5.1500077E+01	6.8879203E-07	1947.3
40	8.2048031E-07	3.6057663E-01	1.3023499E-02	2.9772696E-01	3.3587822E+00	5.1502729E+01	1.8576978E-06	1961.1
43	1.0448326E-06	3.8831329E-01	1.6584648E-02	3.0026253E-01	3.3304188E+00	5.1505934E+01	4.7130200E-06	1977.8
46	1.3133282E-06	4.1604996E-01	2.0846483E-02	3.0329700E-01	3.2970982E+00	5.1509769E+01	1.1319014E-05	1997.8
49	1.6319571E-06	4.4378663E-01	2.5904085E-02	3.0689803E-01	3.2584112E+00	5.1514322E+01	2.[illegible]1678E-05	2021.5
52	2.0073249E-06	4.7152329E-01	3.1862306E-02	3.1114027E-01	3.2139844E+00	5.1519694E+01	5.6[illegible]548E-05	2049.4
55	2.4467404E-06	4.9925996E-01	3.8837106E-02	3.1610630E-01	3.1634927E+00	5.1525961E+01	1.1852772E-04	2082.1
58	2.9583208E-06	5.2699661E-01	4.6957482E-02	3.2188786E-01	3.1066719E+00	5.1533270E+01	2.3931230E-04	2120.2
61	3.5511197E-06	5.5473328E-01	5.6366988E-02	3.2858720E-01	3.0433321E+00	5.1541738E+01	4.6662053E-04	2164.4
64	4.2352805E-06	5.8246994E-01	6.7226686E-02	3.3631894E-01	2.9733680E+00	5.1551512E+01	8.8094588E-04	2215.3
67	5.0222227E-06	6.1020660E-01	7.9717834E-02	3.4521208E-01	2.8967698E+00	5.1562744E+01	1.6141320E-03	2273.9
70	5.9248659E-06	6.3794327E-01	9.4045506E-02	3.5541256E-01	2.8136315E+00	5.1575649E+01	2.8764664E-03	2341.0
73	6.9579006E-06	6.6567993E-01	1.1044288E-01	3.6708631E-01	2.7241549E+00	5.1590406E+01	4.9953166E-03	2417.8
76	8.1381152E-06	6.9341660E-01	1.2917648E-01	3.8042295E-01	2.6286531E+00	5.1607267E+01	8.4692361E-03	2505.8
79	9.4847989E-06	7.2115326E-01	1.5055239E-01	3.9564029E-01	2.5275484E+00	5.1626505E+01	1.4022859E-02	2606.0
82	1.1020216E-05	7.4889992E-01	1.7492410E-01	4.1298977E-01	2.4213674E+00	5.1648439E+01	2.2909066E-02	2720.3
85	1.2770207E-05	7.7662659E-01	2.0270173E-01	4.3276313E-01	2.3107328E+00	5.1673439E+01	3.6348490E-02	2850.5
88	1.4764906E-05	8.0436325E-01	2.3436364E-01	4.5530058E-01	2.1963512E+00	5.1701935E+01	5.6918699E-02	2999.0
91	1.7039638E-	8.3209991E-01	2.7047049E-01	4.8100086E-01	2.0789983E+00	5.1734431E+01	8.7711798E-02	3168.3
94	1.9636013E-05	8.5983658E-01	3.1168280E-01	5.1033357E-01	1.9595026E+00	5.1771522E+01	1.3320651E-01	3361.5
97	2.2603297E-05	8.8757325E-01	3.5878257E-01	5.4385466E-01	1.8387265E+00	5.1813912E+01	1.9965240E-01	3582.3
100	2.6000114E-05	9.1530991E-01	4.1270030E-01	5.8222552E-01	1.7175474E+00	5.1862438E+01	2.9574123E-01	3835.0
103	2.9896580E-05	9.4304658E-01	4.7454897E-01	6.2623705E-01	1.5968394E+00	5.1918102E+01	4.3354519E-01	4124.9
106	3.4376994E-05	9.7078324E-01	5.4566666E-01	6.7683987E-01	1.4774543E+00	5.1982108E+01	6.2984069E-01	4458.2
109	3.9543241E-05	9.9851990E-01	6.2767062E-01	7.3518263E-01	1.3602062E+00	5.2055911E+01	7.8507296E-01	4842.5
112	4.5519132E-05	1.0262566E+00	7.2252604E-01	8.0266069E-01	1.2458564E+00	5.2141281E+01	6.5699807E-01	5287.0
115	5.2455955E-05	1.0539932E+00	8.3263436E-01	8.8097850E-01	1.1351015E+00	5.2240378E+01	4.2222421E-01	5802.9
118	6.0539630E-05	1.0817299E+00	9.6094670E-01	9.7222978E-01	1.0285634E+00	5.2355860E+01	2.3064180E-01	6403.9
121	6.9999987E-05	1.1094666E+00	1.0000000E+00	1.0000000E+00	1.0000000E+00	5.2491008E+01	1.0429851E-01	6586.8

NO. ITERATIONS = 0

POINT WAS ADDED TO BOUNDARY LAYER IN SUBROUTINE MOMNTM AT STATION 1 AND ITERATION 0

PERFECT GAS SAMPLE CASE

STATION	X	S	DS	Rw	THETAw	ZETA	ZETA
20	-3,54489$_{03}$+00	6,7$_{100}$533-03	9,321$_{8}$082-04	1,72279$_{00}$+00	0,0000000	5,0223$_{047}$-04	3,4177928-0

EDGE AND WALL CONDITIONS

UE	=	,3688902+03	ME	=	,7115401-01	DELTA*	=	,2646370-04	CF = ,5577028
TE	=	,65$_{8}$6832+04	RHOE	=	,1968623-01	THETA	=	,3176078-04	ST = ,3906038
HE	=	,1414627+09	MUE	=	,1788394-05	TAUW	=	,7470154+01	
PE	=	,4446425+06	TW	=	,1900000+04	QW	=	,2857158+07	
			MDOTW	=	,2957333-01				

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
1	0,0000000	-0,0000000	0,0000000	2,8845429-01	3,4667536+00	2,0270953+01	0,0000000	1900,
4	6,6289758-09	2,7736664-02	1,5372457-04	2,8854629-01	3,4656484+00	2,0270953+01	9,9888716-14	1900,
7	1,9984554-08	5,5473328-02	4,6424999-04	2,8873217-01	3,4634172+00	2,0270959+01	3,5950057-12	1901,
10	4,3561343-08	8,3209991-02	1,0132436-03	2,8906082-01	3,4594795+00	2,0270987+01	5,8759854-11	1904,
13	8,1593774-08	1,1094666-01	1,8996897-03	2,8959131-01	3,4531421+00	2,0271078+01	6,0538707-10	1907,
16	1,3906100-07	1,3868332-01	3,2400763-03	2,9039309-01	3,4436081+00	2,0271321+01	4,5454686-09	1912,
19	2,2169629-07	1,6641998-01	5,1687033-03	2,9154593-01	3,42999$_{12}$+00	2,0271895+01	2,6946306-08	1920,
22	3,3800100-07	1,9415665-01	7,8381567-03	2,9313971-01	3,4113426+00	2,0273122+01	1,3262822-07	1930,
25	4,8926492-07	2,2189331-01	1,1420000-02	2,9527484-01	3,3866753+00	2,0275535+01	5,6086044-07	1944,
28	6,8959409-07	2,4962997-01	1,6105749-02	2,9806222-01	3,3550041+00	2,0279972+01	2,0885896-06	1963,
31	9,4594860-07	2,7736664-01	2,2108193-02	3,0162335-01	3,3153931+00	2,0287681+01	6,9759969-06	1986,
34	1,2681919-06	3,0510330-01	2,9663029-02	3,0609082-01	3,2670040+00	2,0300421+01	2,1196837-05	2016,
37	1,6671546-06	3,3283997-01	3,9030844-02	3,1160787-01	3,2091615+00	2,0320564+01	5,9246858-05	2052,
40	2,1547151-06	3,6057663-01	5,0497352-02	3,1832892-01	3,1414047+00	2,0351154+01	1,5367825-04	2096,
43	2,7439010-06	3,8831329-01	6,4374458-02	3,2641885-01	3,0639485+00	2,0398895+01	3,7250279-04	2150,
46	3,4490142-06	4,1604996-01	8,0991940-02	3,3605110-01	2,9757378+00	2,0459019+01	8,4826131-04	2213,
49	4,2857855-06	4,4378663-01	1,0068159-01	3,4740388-01	2,8784939+00	2,0544957+01	1,8216899-03	2288,
52	5,2715626-06	4,7152329-01	1,2374347-01	3,6065269-01	2,7727506+00	2,0657801+01	3,6986388-03	2375,
55	6,4255395-06	4,9925996-01	1,5039295-01	3,7595618-01	2,6598702+00	2,0800566+01	7,1102989-03	2476,
58	7,7690331-06	5,2699661-01	1,8069652-01	3,9345080-01	2,5416138+00	2,0974485+01	1,2958345-02	2591,
61	9,3258196-06	5,5473328-01	2,1452130-01	4,1321399-01	2,4200536+00	2,1178629+01	2,2429992-02	2721,
64	1,1122538-05	5,8246994-01	2,5152774-01	4,3527183-01	2,2974149+00	2,1410154+01	3,6990406-02	2867,
67	1,3189176-05	6,1020660-01	2,9121757-01	4,5958415-01	2,1758800+00	2,1665076+01	5,8385281-02	3027,
70	1,5559664-05	6,3794327-01	3,3301310-01	4,8604956-01	2,0574034+00	2,1939141+01	8,8669362-02	3201,
73	1,8272582-05	6,6567993-01	3,7633006-01	5,1451193-01	1,9435895+00	2,2228403+01	1,3027050-01	3389,
76	2,1372021-05	6,9341660-01	4,2062015-01	5,4476581-01	1,8356511+00	2,2529464+01	1,8607745-01	3588,
79	2,4908630-05	7,2115326-01	4,6538394-01	5,7655946-01	1,7344294+00	2,2839678+01	2,5945789-01	3797,
82	2,8940886-05	7,4888992-01	5,1016644-01	6,0958786-01	1,6404525+00	2,3157477+01	3,5429029-01	4015,
85	3,3536646-05	7,7662659-01	5,5454653-01	6,4350031-01	1,5540008+00	2,3482673+01	4,7492169-01	4238,
88	3,8775052-05	8,0436325-01	5,9812713-01	6,7788995-01	1,4751657+00	2,3816877+01	6,2602547-01	4465,
91	4,4746870-05	8,3209991-01	6,4052532-01	7,1230043-01	1,4039019+00	2,4163888+01	8,1232335-01	4691,
94	5,1567373-05	8,5983658-01	6,8136997-01	7,4623213-01	1,3400655+00	2,4529935+01	1,0375394+00	4915,
97	5,9359946-05	8,8757325-01	7,2024708-01	7,7911900-01	1,2835010+00	2,4924614+01	1,3142744+00	5131,
100	6,8280540-05	9,1530991-01	7,5750473-01	8,1087980-01	1,2332284+00	2,5373366+01	1,5103830+00	5341,
103	7,8513294-05	9,4304658-01	7,9627572-01	8,4332895-01	1,1857769+00	2,5976898+01	1,4835120+00	5554,
106	9,0279593-05	9,7078324-01	8,3883000-01	8,7737949-01	1,1394979+00	2,6866576+01	1,3571334+00	5780,
109	1,0384700-04	9,9851990-01	8,8482504-01	9,1281701-01	1,0955098+00	2,8222784+01	1,1382468+00	6012,
112	1,1954067-04	1,0262566+00	9,3169905-01	9,4885134-01	1,0561320+00	3,0008990+01	8,3502707-01	6236,
115	1,3775790-04	1,0539932+00	9,7175606-01	9,7516163-01	1,0254710+00	3,1810635+01	5,1971341-01	6423,
118	1,5898695-04	1,0817299+00	9,9406277-01	9,9247741-01	1,0075796+00	3,2618295+01	2,7640411-01	6537,
121	1,8383139-04	1,1094666+00	9,9961895-01	9,9885635-01	1,0011449+00	3,2387110+01	1,3054349-01	6579,
124	2,1304186-04	1,1372032+00	1,0000000+00	1,0000000+00	1,0000000+00	3,2138705+01	5,2948610-02	6586,

NO. ITERATIONS = 1

PERFECT GAS SAMPLE CASE

STATION	X	S	DS	R*	THETA*	ZETA	ZETAP
162	-5.0000001-02	3.6816102+00	1.5028360-02	1.0011752+00	-4.7140803-02	1.9770218-02	-2.1283059-03

EDGE AND WALL CONDITIONS

UE =	.5044406+04	ME =	.1019676+01		
TE =	.5997587+04	RHOE =	.1223263-01		
HE =	.1288077+09	MUE =	.1701634-05		
PE =	.2515755+06	TW =	.1700000+04		
		MDOTW =	.1666014-00		

PROFILE PARAMETERS

DELTA* =	.7763090-03	CF =	.2109673-02
THETA =	.1017314-02	ST =	.8128967-03
TAUW =	.3283410+03		
GW =	.5267923+07		

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
1	0.0000000	-0.0000000	0.0000000	2.8344734-01	3.5279921+00	2.6066917+00	0.0000000	1700.0
4	2.6074851-07	2.7736664-02	2.1212896-02	2.9132573-01	3.4325839+00	2.8066005+00	3.1255540-04	1747.3
7	7.8668858-07	5.5473328-02	6.5237934-02	3.0728053-01	3.2543552+00	2.8059106+00	8.0215106-03	1842.9
10	1.7147849-06	8.3209991-02	1.3588089-01	3.3385472-01	2.9953148+00	2.8035574+00	6.7081210-02	2002.3
13	3.2119251-06	1.1094666-01	2.1305307-01	3.6795720-01	2.7177073+00	2.7986639+00	2.8280284-01	2206.9
16	5.4741129-06	1.3868332-01	2.7809369-01	4.0212528-01	2.4867872+00	2.7908685+00	8.0885532-01	2411.8
19	8.7270368-06	1.6641998-01	3.2934483-01	4.3717109-01	2.3163317+00	2.7795414+00	1.6407348+00	2569.3
22	1.3226622-05	[illegible]	3.7026554-01	4.5591419-01	2.1933952+00	2.7636710+00	3.5435652+00	2734.4
25	1.9259831-05	[illegible]	4.0419693-01	4.7560675-01	2.1025774+00	2.7420070+00	6.1931852+00	2852.5
28	2.7145755-05	2.4962997-01	4.3359507-01	4.9199560-01	2.0325385+00	2.7131284+00	9.7509301+00	2950.8
31	3.7237107-05	2.7736664-01	4.5994417-01	5.0609986-01	1.9758946+00	2.6754818+00	1.4303696+01	3035.4
34	4.9922161-05	3.0510330-01	4.8432449-01	5.1867213-01	1.9280002+00	2.6274239+00	1.9937797+01	3110.8
37	6.5627260-05	3.3283997-01	5.0724500-01	5.3023288-01	1.8859637+00	2.5672740+00	2.6820334+01	3180.1
40	8.4819998-05	3.6057663-01	5.2898929-01	5.4112433-01	1.8480041+00	2.4933507+00	3.5181250+01	3245.4
43	1.0801320-04	3.8831329-01	5.4970650-01	5.5155949-01	1.8130410+00	2.4039810+00	4.5271818+01	3308.0
46	1.3576986-04	4.1604996-01	5.6948924-01	5.6166635-01	1.7804164+00	2.2974845+00	5.7341284+01	3368.6
49	1.6870923-04	4.4378663-01	5.8840881-01	5.7152218-01	1.7497134+00	2.1721553+00	7.1637370+01	3427.8
52	2.0751417-04	4.7152329-01	6.0652754-01	5.8117947-01	1.7206389+00	2.0262497+00	8.8413388+01	3485.7
55	2.5294027-04	4.9925996-01	6.2390164-01	5.9067909-01	1.6929666+00	1.8579832+00	1.0793353+02	3542.6
58	3.0582668-04	5.2699661-01	6.4059214-01	6.0005715-01	1.6665079+00	1.6655221+00	1.3047357+02	3598.9
61	3.6710932-04	5.5473328-01	6.5661559-01	6.0934682-01	1.6411015+00	1.4469622+00	1.5632155+02	3654.6
64	4.3768861-04	5.8246994-01	6.7204400-01	6.1858016-01	1.6166053+00	1.2003014+00	1.8577691+02	3710.0
67	5.1918969-04	6.1020660-01	6.8690561-01	6.2778819-01	1.5928939+00	9.2340121-01	2.1915004+02	3765.2
70	6.1250356-04	6.3794327-01	7.0123504-01	6.3700181-01	1.5698542+00	6.1393985-01	2.5676498+02	3820.5
73	7.1929710-04	6.6567993-01	7.1506371-01	6.4625284-01	1.5473820+00	2.6936267-01	2.9897785+02	3876.0
76	8.4130599-04	6.9341660-01	7.2842188-01	6.5557543-01	1.5253775+00	-1.1322994-01	3.4618184+02	3931.9
79	9.8052400-04	7.2115326-01	7.4133748-01	6.6500656-01	1.5037446+00	-5.3717996-01	3.9834553+02	3988.4
82	1.1392531-03	7.4888992-01	7.5381631-01	6.7457249-01	1.4824203+00	-1.0063434+00	4.5554768+02	4045.8
85	1.3201644-03	7.7662659-01	7.6638363-01	6.8472534-01	1.4604396+00	-1.5251340+00	4.7919462+02	4106.7
88	1.5263734-03	8.0436325-01	7.7993433-01	6.9630758-01	1.4361469+00	-2.0976891+00	4.7784129+02	4176.2
91	1.7615317-03	8.3209991-01	7.9474302-01	7.0975143-01	1.4089440+00	-2.7277403+00	4.7701661+02	4256.8
94	2.0299409-03	8.5983658-01	8.1082911-01	7.2532769-01	1.3786872+00	-3.4196768+00	4.7511205+02	4350.2
97	2.3366943-03	8.8757325-01	8.2818463-01	7.4333008-01	1.3452974+00	-4.1787906+00	4.7077079+02	4458.2
100	2.6878519-03	9.1530991-01	8.4680766-01	7.6411056-01	1.3087111+00	-5.0113945+00	4.6108575+02	4582.8
103	3.0906626-03	9.4304658-01	8.6678586-01	7.8518607-01	1.2687359+00	-5.9247617+00	4.4036466+02	4727.2
106	3.5538410-03	9.7078324-01	8.8846842-01	8.1649906-01	1.2247411+00	-6.9264280+00	3.9957255+02	4897.0
109	4.0879197-03	9.9851990-01	9.1270878-01	8.5088097-01	1.1752525+00	-8.0221414+00	3.3054861+02	5103.2
112	4.7056982-03	1.0262566+00	9.4077115-01	8.9417867-01	1.1183447+00	-9.2136115+00	2.3800632+02	5362.9
115	5.4228163-03	1.0539932+00	9.7186666-01	9.4648179-01	1.0565443+00	-1.0509863+01	1.4525802+02	5676.[illegible]
118	6.2584943-03	1.0817299+00	9.9532393-01	9.8996689-01	1.0101348+00	-1.1989735+01	7.6052429+01	5937.4
121	7.2364914-03	1.1094666+00	1.0000194+00	1.0000270+00	9.9997297-01	-1.3815204+01	3.5509660+01	5997.7
124	8.3863570-03	1.1372032+00	1.0000000+00	1.0000000+00	1.0000000+00	-1.6010734+01	1.4342751+01	5997.6

NO. ITERATIONS = 1

PERFECT GAS SAMPLE CASE

STATION	X	S	DS	RW	THETAW	ZETA	ZETAP
232	5.2000000 2	3.7893050+00	2.3453173-03	1.0232216+00	5.4979727-01	3.9642359-02	-5.8697811-02

EDGE AND WALL CONDITIONS

UE	= .9273300+04	ME	= .2143212+01				
TE	= .4587957+04	RHOE	= .3129670-02				
HE	= .9853587+08	MUE	= .1473777-05				
PE	= .4923681+05	TW	= .1900000+04				
		MDOTW	= .3134218-01				

PROFILE PARAMETERS

DELTA*	= .1401666-02	CF	= .3185448-
THETA	= .1798396-02	ST	= .9235926-
TAUW	= .4286545+03		
QW	= .2699923+07		

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
1	0.0000000	-0.0000000	0.0000000	4.1412764-01	2.4147144+00	2.6308438-01	0.0000000	1900.0
4	5.2324231-07	2.7736664-02	2.7816500-02	4.2372701-01	2.3600100+00	2.6312380-01	1.2121479-03	1944.0
7	1.5774328-06	5.5473328-02	5.5776651-02	4.4173585-01	2.2637963+00	2.6328805-01	3.1959591-02	2026.7
10	3.4384102-06	8.3209991-02	1.7184792-01	4.6821849-01	2.1357550+00	2.6343715-01	2.8297676-01	2148.2
13	6.4404089-06	1.1094666-01	2.6749120-01	4.9673698-01	2.0131378+00	2.6382598-01	1.2449530+00	2279.0
16	1.0976447-05	1.3868332-01	3.4534452-01	5.1966327-01	1.9243230+00	2.6463548-01	3.6098637+00	2384.2
19	1.7499065-05	1.6641998-01	4.0349738-01	5.3528912-01	1.8681493+00	2.6585412-01	8.1409302+00	2455.9
22	2.6521433-05	1.9415665-01	4.4792714-01	5.4552237-01	1.8331054+00	2.6779967-01	1.5480830+01	2502.8
25	3.8618954-05	2.2189331-01	4.8380020-01	5.5247329-01	1.8100422+00	2.7074704-01	2.5919589+01	2534.7
28	5.4431456-05	2.4962997-01	5.1444677-01	5.5755643-01	1.7935404+00	2.7485034-01	3.9446430+01	2558.0
31	7.4666185-05	2.7736664-01	5.4180702-01	5.6162035-01	1.7805622+00	2.8007611-01	5.6091958+01	2576.7
34	1.0010169-04	3.0510330-01	5.6691562-01	5.6518324-01	1.7693376+00	2.8612255-01	7.6205764+01	2593.0
37	1.3159285-04	3.3283997-01	5.9027665-01	5.6838740-01	1.7587445+00	2.9235032-01	1.0039737+02	2608.7
40	1.7007727-04	3.6057663-01	6.1213141-01	5.7208199-01	1.7480011+00	2.9769196-01	1.2928682+02	2624.7
43	2.1658325-04	3.8831329-01	6.3261379-01	5.7586481-01	1.7365187+00	3.0051596-01	1.6335167+02	2642.0
46	2.7223967-04	4.1604996-01	6.5181540-01	5.8010093-01	1.7238379+00	2.9840937-01	2.0286836+02	2661.3
49	3.3828820-04	4.4378663-01	6.6980515-01	5.8493013-01	1.7096059+00	2.8792489-01	2.4792008+02	2683.6
52	4.1609816-04	4.7152329-01	6.8663523-01	5.9046577-01	1.6935782+00	2.6437961-01	2.9836594+02	2709.0
55	5.0718456-04	4.9925996-01	7.0234575-01	5.9678857-01	1.6756353+00	2.2177069-01	3.5383805+02	2738.0
58	6.1323000-04	5.2699661-01	7.1697007-01	6.0393652-01	1.6558031+00	1.5296952-01	4.1380746+02	2770.8
61	7.3611122-04	5.5473328-01	7.3058233-01	6.1189394-01	1.6342701+00	5.0295906-02	4.7777910+02	2807.3
64	8.7793083-04	5.8246994-01	7.4310554-01	6.2058366-01	1.6113862+00	-9.3483524-02	5.4569352+02	2847.2
67	1.0410560-03	6.1020660-01	7.5472627-01	6.2987011-01	1.5876289+00	-2.8397179-01	6.1824334+02	2889.8
70	1.2281648-03	6.3794327-01	7.6549238-01	6.3958025-01	1.5635254+00	-5.2429197-01	6.9778891+02	2934.4
73	1.4423025-03	6.6567993-01	7.7552488-01	6.4954383-01	1.5395419+00	-8.1526606-01	7.8015396+02	2980.1
76	1.6869492-03	6.9341660-01	7.8496536-01	6.5963878-01	1.5159812+00	-1.1567829+00	8.9443020+02	3026.4
79	1.9661029-03	7.2115326-01	7.9396074-01	6.6981648-01	1.4929462+00	-1.5496551+00	1.0220142+03	3073.1
82	2.2843794-03	7.4888992-01	8.0264526-01	6.8009339-01	1.4703862+00	-1.9988159+00	1.1751115+03	3120.2
85	2.6471347-03	7.7662659-01	8.1111665-01	6.9050939-01	1.4482062+00	-2.5034607+00	1.3604513+03	3168.0
88	3.0606158-03	8.0436325-01	8.1967810-01	7.0141298-01	1.4256936+00	-3.0759736+00	1.4763721+03	3218.1
91	3.5321448-03	8.3209991-01	8.2913367-01	7.1380940-01	1.4008164+00	-3.7202512+00	1.4827330+03	3275.2
94	4.0703470-03	8.5983658-01	8.3998166-01	7.2865250-01	1.3723963+00	-4.4431406+00	1.4769158+03	3343.0
97	4.6854351-03	8.8757325-01	8.5231884-01	7.4607386-01	1.3403499+00	-5.2529120+00	1.4636524+03	3423.0
100	5.3895608-03	9.1530991-01	8.6618325-01	7.6640826-01	1.3047876+00	-6.1579062+00	1.4340458+03	3516.2
103	6.1972588-03	9.4304658-01	8.8169903-01	7.9008760-01	1.2656824+00	-7.1658319+00	1.3706240+03	3624.9
106	7.1260032-03	9.7078324-01	8.9925279-01	8.1800435-01	1.2224874+00	-8.2823383+00	1.2454669+03	3753.0
109	8.1969142-03	9.9851990-01	9.1969413-01	8.5193022-01	1.1738050+00	-9.5068654+00	1.0328180+03	3908.6
112	9.4356510-03	1.0262566+00	9.4425460-01	8.9456771-01	1.1178584+00	-1.0828960+01	7.4608402+02	4104.2
115	1.0873589-02	1.0539932+00	9.7242191-01	9.4600875-01	1.0570727+00	-1.2256470+01	4.5687763+02	4340.2
118	1.2549253-02	1.0817299+00	9.9496131-01	9.8969687-01	1.0104104+00	-1.3966840+01	2.3984209+02	4540.7
121	1.4510290-02	1.1094666+00	1.0001780+00	1.0003626+00	9.9963749-01	-1.6319422+01	1.1235788+02	4588.4
124	1.6815948-02	1.1372032+00	1.0000000+00	1.0000000+00	1.0000000+00	-1.9233706+01	4.5350172+01	4588.0

NO. ITERATIONS = 1

PERFECT GAS SAMPLE CASE

STATION / X / S	RN / THETA* / DS	UE / TE / HE	ME / PE / RHOE	MUE / CCTV / T*	CF / TAU* / ----	ST / GM / SUMGM	DELTA* / THETA / ADDMAS	ZETA / ZETAP / DUEDS	R*PR / XPR
.0	1.7228+00	3.6846+02	7.1071-02	1.7884-06	3.8303-03	3.1944-03	1.9091-05	1.9124-04	1.7271+00
-3.5516+00	0.0000	6.5869+03	4.4463+05	0.0000	5.1183+00	2.5338+06	1.7454-05	4.6822-04	-3.5606+00
0.0000	6.5500-05	1.4146+08	1.9686-02	1.9000+03	0.0000	0.0000	0.0000	-0.0000	
1.0	1.7228+00	3.6846+02	7.1071-02	1.7884-06	3.4[illegible]03	3.0910-03	1.9377-05	2.0569-04	1.7271+00
-3.5515+00	0.0000	6.5868+03	4.4463+05	2.9581-02	4.66[illegible]+00	2.2583+06	1.7958-05	2.2061-01	-3.5605+00
6.5500-05	6.5500-05	1.4146+08	1.9686-02	1.9000+03	0.0000	1.5146+02	1.1112-06	6.4382-02	
2.0	1.7228+00	3.6847+02	7.1072-02	1.7884-06	3.6796-03	3.1703-03	1.9502-05	2.2497-04	1.7271+00
-3.5515+00	0.0000	6.5868+03	4.4463+05	2.9601-02	4.9172+00	2.3163+06	1.8410-05	2.5593-01	-3.5604+00
1.4082-04	7.5325-05	1.4146+08	1.9686-02	1.9000+03	0.0000	3.2498+02	2.3890-06	6.4392-02	
3.0	1.7228+00	3.6847+02	7.1073-02	1.7884-06	3.7485-03	3.3082-03	1.9614-05	2.3900-04	1.7271+00
-3.5514+00	0.0000	6.5868+03	4.4463+05	2.9569-02	5.0095+00	2.4171+06	1.8373-05	1.6192-01	-3.5603+00
2.2745-04	8.6624-05	1.4146+08	1.9686-02	1.9000+03	0.0000	5.3145+02	3.8586-06	6.4422-02	
4.0	1.7228+00	3.6848+02	7.1075-02	1.7884-06	4.3059-03	3.7095-03	1.8168-05	2.4315-04	1.7271+00
-3.5513+00	0.0000	6.5868+03	4.4463+05	2.9544-02	5.7546+00	2.7103+06	1.8091-05	4.1697-02	-3.5602+00
3.2707-04	9.9617-05	1.4146+08	1.9686-02	1.9000+03	0.0000	7.8865+02	5.5486-06	6.4396-02	
5.0	1.7228+00	3.6849+02	7.1076-02	1.7884-06	4.6646-03	4.0439-03	1.7395-05	2.4116-04	1.7271+00
-3.5512+00	0.0000	6.5868+03	4.4463+05	2.9542-02	6.2342+00	2.9547+06	1.7912-05	-1.7356-02	-3.5601+00
4.4133-04	1.1456-04	1.4146+08	1.9686-02	1.9000+03	0.0000	1.1155+03	7.4928-06	6.4419-02	
6.0	1.7228+00	3.6849+02	7.1078-02	1.7884-06	5.1787-03	4.3580-03	1.7023-05	2.4012-04	1.7271+00
-3.5510+00	0.0000	6.5868+03	4.4463+05	2.9542-02	6.9216+00	3.1042+06	1.8091-05	-7.9334-03	-3.5600+00
5.7337-04	1.3174-04	1.4146+08	1.9686-02	1.9000+03	0.0000	1.5227+03	9.7270-06	6.4414-02	
7.0	1.7228+00	3.6850+02	7.1080-02	1.7884-06	5.2688-03	4.4417-03	1.7021-05	2.4585-04	1.7271+00
-3.5509+00	0.0000	6.5868+03	4.4463+05	2.9546-02	7.0424+00	3.2455+06	1.8565-05	3.7887-02	-3.5598+00
7.2488-04	1.5151-04	1.4146+08	1.9686-02	1.9000+03	0.0000	2.0133+03	1.2297-05	6.4422-02	
8.0	1.7228+00	3.6852+02	7.1082-02	1.7884-06	5.5075-03	4.5218-03	1.7192-05	2.5936-04	1.7271+00
-3.5507+00	0.0000	6.5868+03	4.4463+05	2.9563-02	7.3618+00	3.3041+06	1.9173-05	7.7847-02	-3.5597+00
8.9911-04	1.7423-04	1.4146+08	1.9686-02	1.9000+03	0.0000	2.5879+03	1.5253-05	6.4427-02	
9.0	1.7228+00	3.6853+02	7.1084-02	1.7884-06	5.5513-03	4.5523-03	1.7329-05	2.7692-04	1.7271+00
-3.5506+00	0.0000	6.5868+03	4.4463+05	2.9573-02	7.4209+00	3.3265+06	1.9719-05	8.7520-02	-3.5594+00
1.0995-03	2.0037-04	1.4146+08	1.9686-02	1.9000+03	0.0000	3.2569+03	1.8652-05	6.4423-02	
10.0	1.7228+00	3.6854+02	7.1087-02	1.7884-06	5.8809-03	4.7067-03	1.7372-05	2.9309-04	1.7271+00
-3.5503+00	0.0000	6.5868+03	4.4463+05	2.9565-02	7.8622+00	3.4395+06	2.0143-05	7.0160-02	-3.5592+00
1.3299-03	2.3[illegible]-04	1.4146+08	1.9686-02	1.9000+03	0.0000	4.0420+03	2.2561-05	6.4427-02	
11.0	1.7[illegible]+00	3.6856+02	7.1[illegible]0-02	1.7884-06	6.0460-03	4.8204-03	1.7426-05	3.0581-04	1.7271+00
-3.5500+00	0.0000	6.5868+03	4.4463+05	2.9555-02	8.0837+00	3.5228+06	2.0544-05	4.7999-02	-3.5590+00
1.5949-03	2.6498-04	1.4146+08	1.9686-02	1.9000+03	0.0000	4.9710+03	2.7057-05	6.4416-02	
12.0	1.7[illegible]+00	[illegible]856+02	7.1094-02	1.7884-06	6.3241-03	4.9213-03	1.7621-05	3.1624-04	1.7271+00
-3.5497+00	0.0000	6.5868+03	4.4463+05	2.9550-02	8.4564+00	3.5967+06	2.1057-05	3.4229-02	-3.5588+00
1.8996-03	3.0473-04	1.4146+08	1.9686-02	1.9000+03	0.0000	6.0635+03	3.2220-05	6.4425-02	

PERFECT GAS SAMPLE CASE

STATION x S	Rw THETAW DS	UE TE ME	RE PE RHOE	MUE CPOTW TW	CF TAUW ----	ST QW SUMQW	DELTA* THETA ADDMAS	ZETA ZETAP DUEDS	AMPR XPR
52.0	1.7228+00	4.2033+02	8.1083-02	1.7883-06	1.9983-03	1.0783-03	7.4267-04	1.0210-02	1.7247+00
-3.0340+00	0.0000	6.5859+03	4.4449+05	2.9558-02	3.4745+00	8.9859+05	6.8182-04	1.1049-02	-3.0617+00
4.9758-01	4.2351-02	1.4144+03	1.9682-02	1.9000+03	0.0000	5.0765+05	8.4412-03	2.2433-01	
53.0	1.7228+00	4.3183+02	8.3302-02	1.7882+06	2.0762-03	1.0972-03	7.6242-04	1.0623-02	1.7246+00
-3.0096+00	0.0000	6.5857+03	4.4438+05	2.9553-02	3.8092+00	9.3911+05	6.8191-04	9.3039-03	-3.0171+00
5.4205-01	4.4469-02	1.4144+03	1.9678-02	1.9000+03	0.0000	5.4880+05	9.1956-03	2.5851-01	
54.0	1.7228+00	4.4558+02	8.5955-02	1.7882+06	2.1844-03	1.1190-03	7.7555-04	1.0980-02	1.7246+00
-2.9629+00	0.0000	6.5854+03	4.4423+05	2.9550-02	4.2267+00	9.8799+05	6.9694-04	7.6454-03	-2.9703+00
5.8874-01	4.6692-02	1.4143+03	1.9672-02	1.9000+03	0.0000	5.9412+05	9.9877-03	2.9440-01	
55.0	1.7228+00	4.6186+02	8.9098-02	1.7881+06	2.2604-03	1.1441-03	7.8224-04	1.1275-02	1.7246+00
-2.9138+00	0.0000	6.5850+03	4.4407+05	2.9547-02	4.7411+00	1.0467+06	7.0684-04	6.0096-03	-2.9212+00
6.3776-01	4.9027-02	1.4142+03	1.9666-02	1.9000+03	0.0000	6.4435+05	1.0819-02	3.3208-01	
56.0	1.7228+00	4.8099+02	9.2792-02	1.7881+06	2.3603-03	1.1696-03	7.8303-04	1.1502-02	1.7246+00
-2.8624+00	0.0000	6.5846+03	4.4387+05	2.9542-02	5.3673+00	1.1139+06	7.1191-04	4.4182-03	-2.8698+00
6.8924-01	5.1478-02	1.4142+03	1.9658-02	1.9000+03	0.0000	7.0035+05	1.1694-02	3.7164-01	
57.0	1.7228+00	5.0221+02	9.6889-02	1.7880+06	2.4407+03	1.1874-03	7.7890-04	1.1656-02	1.7246+00
-2.8109+00	0.0000	6.5841+03	4.4364+05	2.9511-02	6.0480+00	1.1802+06	7.1313-04	2.9823-03	-2.8180+00
7.4072-01	5.1478-02	1.4140+03	1.9650-02	1.9000+03	0.0000	7.5982+05	1.2578-02	4.1217-01	
58.0	1.7228+00	5.2551+02	1.0139-01	1.7879+06	2.5050-03	1.1986-03	7.7189-04	1.1750-02	1.7246+00
-2.7594+00	0.0000	6.5836+03	4.4340+05	3.0500-02	6.7935+00	1.2461+06	7.1183-04	1.8222-03	-2.7664+00
7.9220-01	5.1478-02	1.4139+03	1.9641-02	1.9000+03	0.0000	8.2272+05	1.3480-02	4.5270-01	
59.0	1.7228+00	5.5054+02	1.0622-01	1.7878+06	2.5628-03	1.2097-03	7.6369-04	1.1807-02	1.7246+00
-2.7079+00	0.0000	6.5829+03	4.4313+05	3.1089-02	7.6241+00	1.3169+06	7.0969-04	1.1043-03	-2.7147+00
8.4368-01	5.1478-02	1.4138+03	1.9631-02	1.9000+03	0.0000	8.8916+05	1.4399-02	4.8814-01	
60.0	1.7228+00	5.7650+02	1.1124-01	1.7877+06	2.6000-03	1.2152-03	7.5669-04	1.1855-02	1.7246+00
-2.6564+00	0.0000	6.5823+03	4.4284+05	3.1677-02	8.4771+00	1.3845+06	7.0916-04	9.4917-04	-2.6631+00
8.9516-01	5.1478-02	1.4136+03	1.9620-02	1.9000+03	0.0000	9.5919+05	1.5335-02	5.0443-01	
61.0	1.7228+00	6.0300+02	1.1636-01	1.7876+06	2.6267-03	1.2185-03	7.5171-04	1.1922-02	1.7247+00
-2.6015+00	0.0000	6.5815+03	4.4252+05	3.2266-02	9.3636+00	1.4511+06	7.1057-04	1.2909-03	-2.6115+00
9.4663-01	5.1478-02	1.4135+03	1.9608-02	1.9000+03	0.0000	1.0327+06	1.6289-02	5.1464-01	
62.0	1.7228+00	6.3001+02	1.2158-01	1.7875+06	2.7086-03	1.2450-03	7.4636-04	1.2012-02	1.7247+00
-2.5535+00	0.0000	6.5808+03	4.4218+05	3.1777-02	1.0533+01	1.5481+06	7.1233-04	1.7534-03	-2.5599+00
9.9811-01	5.1478-02	1.4133+03	1.9595-02	1.9000+03	0.0000	1.1104+06	1.7228-02	5.2486-01	
63.0	1.7228+00	6.5756+02	1.2690-01	1.7874+06	2.8389-03	1.2927-03	7.3858-04	1.2111-02	1.7247+00
-2.5020+00	0.0000	6.5799+03	4.4183+05	2.9923-02	1.2018+01	1.6766+06	7.1304-04	1.9244-03	-2.5083+00
1.0496+00	5.1478-02	1.4131+03	1.9582-02	1.9000+03	0.0000	1.1940+06	1.8113-02	5.3507-01	
64.0	1.7228+00	6.8563+02	1.3233-01	1.7873+06	2.9632-03	1.3385-03	7.2860-04	1.2199-02	1.7247+00
-2.4505+00	3.0235-05	6.5791+03	4.4144+05	2.7812-02	1.3628+01	1.8087+06	7.1256-04	1.7048-03	-2.4567+00
1.1011+00	5.1478-02	1.4130+03	1.9568-02	1.9000+03	0.0000	1.2844+06	1.8935-02	5.4529-01	

PERFECT GAS SAMPLE CASE

STATION X S	QA THETA QS	UE TE HE	PE PE RHOE	MUE MOOTA TW	CF TAUW	ST QW SIGMA	DELTA* THETA ADIMAS	ZETA ZETAP DEDS	RNPR XPR
156.0	1.0093+00	4.4235+03	8.8415-01	1.7222-06	1.9173-03	7.8162-04	7.6324-04	1.9561-02	1.0093+00
-1.4000-01	-1.3934-01	6.1344+03	2.9286+05	1.7095-01	2.5225+02	4.9842+06	1.0212-03	5.6443-03	-1.4035-01
3.5912+00	1.5163-02	1.3175+08	1.3447-02	1.7000+03	0.0000	8.9664+06	7.8895-02	4.5769+00	
157.0	1.0074+00	4.4926+03	8.9899-01	1.7200-06	1.9233-03	7.8267-04	7.7042-04	1.9609-02	1.0074+00
-1.2500-01	-1.1751-01	6.1201+03	2.7972+05	1.7023-01	2.5870+02	4.9232+06	1.0244-03	5.1700-03	-1.2532-01
3.6063+00	1.5132-02	1.3144+08	1.3329-02	1.7000+03	0.0000	8.6102+06	7.9761-02	4.5601+00	
158.0	1.0057+00	4.5696+03	9.1562-01	1.7176-06	1.9413-03	7.8585-04	7.7519-04	1.9631-02	1.0057+00
-1.1000-01	-1.0350-01	6.1039+03	2.7606+05	1.6950-01	2.6733+02	4.9741+06	1.0271-03	1.4978-03	-1.1028-01
3.6214+00	1.5104-02	1.3109+08	1.3190-02	1.7000+03	0.0000	8.6542+06	8.0620-02	5.0993+00	
159.0	1.0043+00	4.6616+03	9.3557-01	1.7146-06	1.9698-03	7.9025-04	7.7753-04	1.9663-02	1.0042+00
-9.5000-02	-8.9646-02	6.0841+03	2.7110+05	1.6878-01	2.7811+02	5.0272+06	1.0298-03	2.0898-03	-9.5240-02
3.6365+00	1.5081-02	1.3067+08	1.2994-02	1.7000+03	0.0000	8.6985+06	8.1472-02	6.1003+00	
160.0	1.0030+00	4.7686+03	9.5889-01	1.7111-06	2.0002-03	7.9452-04	7.7884-04	1.9737-02	1.0030+00
-8.0000-02	-7.5588-02	6.0606+03	2.6473+05	1.6805-01	2.8968+02	5.0685+06	1.0334-03	4.9163-03	-8.0202-02
3.6515+00	1.5060-02	1.3016+08	1.2738-02	1.7000+03	0.0000	8.7431+06	8.2319-02	7.1029+00	
161.0	1.0020+00	4.8905+03	9.8565-01	1.7070-06	2.0415-03	8.0194-04	7.8101-04	1.9802-02	1.0020+00
-6.5000-02	-6.1368-02	6.0332+03	2.5862+05	1.6733-01	3.0520+02	5.1490+06	1.0280-03	4.3371-03	-6.5164-02
3.6666+00	1.5043-02	1.2957+08	1.2501-02	1.7000+03	0.0000	8.7881+06	8.3160-02	8.1064+00	
162.0	1.0012+00	5.0444+03	1.0197+00	1.7016-06	2.1097-03	8.1298-04	7.7631-04	1.9770-02	1.0012+00
-5.0000-02	-4.7141-02	5.9976+03	2.5158+05	1.6660-01	3.2834+02	5.2679+06	1.0173-03	-2.1283-03	-5.0126-02
3.6816+00	1.5028-02	1.2881+08	1.2233-02	1.7000+03	0.0000	8.8339+06	8.3996-02	1.0240+01	
163.0	1.0011+00	5.0688+03	1.0251+00	1.7008-06	2.1254-03	8.1505-04	7.7054-04	1.9751-02	1.0011+00
-4.0000-02	-4.5243-02	5.9919+03	2.5031+05	1.6619-01	3.3263+02	5.2858+06	1.0164-03	-9.5837-03	-4.8121-02
3.6936+00	2.0022-03	1.2863+08	1.2183-02	1.7000+03	0.0000	8.8401+06	8.4107-02	1.2164+01	
164.0	1.0010+00	5.0943+03	1.0308+00	1.6999-06	2.1301-03	8.1529-04	7.6913-04	1.9694-02	1.0010+00
-4.6000-02	-4.3346-02	5.9858+03	2.4894+05	1.6609-01	3.3523+02	5.2902+06	1.0160-03	-2.8321-02	-4.6116-02
3.6956+00	2.0020-03	1.2855+08	1.2128-02	1.7000+03	0.0000	8.8463+06	8.4218-02	1.2747+01	
165.0	1.0009+00	5.1210+03	1.0367+00	1.6989-06	2.1499-03	8.1903-04	7.6795-04	1.9657-02	1.0009+00
-4.4000-02	-4.1448-02	5.9795+03	2.4747+05	1.6600-01	3.4023+02	5.3163+06	1.0154-03	-1.8853-02	-4.4111-02
3.6876+00	2.0019-03	1.2842+08	1.2069-02	1.7000+03	0.0000	8.8525+06	8.4329-02	1.3329+01	
166.0	1.0008+00	5.1488+03	1.0429+00	1.6979-06	2.1545-03	8.1855-04	7.6697-04	1.9654-02	1.0008+00
-4.2000-02	-3.9550-02	5.9729+03	2.4588+05	1.6590-01	3.4285+02	5.3137+06	1.0147-03	-1.4889-03	-4.2106-02
3.6896+00	2.0017-03	1.2828+08	1.2005-02	1.7000+03	0.0000	8.8588+06	8.4440-02	1.3912+01	
167.0	1.0008+00	5.1778+03	1.0494+00	1.6968-06	2.1723-03	8.2154-04	7.6605-04	1.9675-02	1.0008+00
-4.0000-02	-3.7652-02	5.9658+03	2.4419+05	1.6580-01	3.4760+02	5.3326+06	1.0141-03	1.0645-02	-4.0101-02
3.6916+00	2.0016-03	1.2813+08	1.1937-02	1.7000+03	0.0000	8.8650+06	8.4550-02	1.4495+01	
168.0	1.0007+00	5.2080+03	1.0562+00	1.6957-06	2.1799-03	8.2173-04	7.6516-04	1.9706-02	1.0007+00
-3.8000-02	-3.5753-02	5.9585+03	2.4240+05	1.6571-01	3.5072+02	5.3321+06	1.0138-03	1.5312-02	-3.8096-02
3.6936+00	2.0014-03	1.2797+08	1.1864-02	1.7000+03	0.0000	8.8712+06	8.4661-02	1.5079+01	

PERFECT GAS SAMPLE CASE

STATION X S	RW THETAW DS	UE TE HE	ME PE RHOE	MUE MDOTW TW	CF TAUW ----	ST QW SUMQW	DELTA* THETA ADDMAS	ZETA ZETAP DYEDS	RWPR XPR
221.0	1.0097+00	9.2379+03	2.1315+00	1.4764-06	3.0943-03	8.2649-04	1.3632-03	4.1656-02	1.0085+00
3.0000-02	5.4899-01	4.6032+03	5.0273+04	7.0783-02	4.2050+02	2.4493+06	1.7730-03	-3.1663-01	3.0076-02
3.7635+00	2.3451-03	9.8862+07	3.1849-03	1.9000+03	0.0000	9.0526+06	8.7965-02	-1.5000+00	
222.0	1.0110+00	9.2343+03	2.1303+00	1.4767-06	3.0563-03	8.3282-04	1.3567-03	4.0097-02	1.0097+00
3.2000-02	5.4872-01	4.6048+03	5.0373+04	6.4353-02	4.1572+02	2.4712+06	1.7796-03	-6.6485-01	3.2081-02
3.7658+00	2.3445-03	9.8695+07	3.1902-03	1.9000+03	0.0000	9.0560+06	8.8016-02	-1.5451+00	
223.0	1.0122+00	9.2303+03	2.1290+00	1.4770-06	3.1054-03	8.5239-04	1.3576-03	3.8918-02	1.0109+00
3.4000-02	5.5095-01	4.6065+03	5.0488+04	5.7941-02	4.2284+02	2.5331+06	1.7781-03	-5.0274-01	3.4086-02
3.7682+00	2.3441-03	9.8931+07	3.1963-03	1.9000+03	0.0000	9.0595+06	8.8062-02	-1.6675+00	
224.0	1.0134+00	9.2263+03	2.1276+00	1.4773-06	3.0689-03	8.5424-04	1.3611-03	3.8435-02	1.0122+00
3.6000-02	5.5372-01	4.6082+03	5.0607+04	5.1543-02	4.1833+02	2.5425+06	1.7731-03	-2.0594-01	3.6091-02
3.7705+00	2.3473-03	9.8969+07	3.2026-03	1.9000+03	0.0000	9.0630+06	8.8103-02	-1.7405+00	
225.0	1.0146+00	9.2263+03	2.1277+00	1.4773-06	3.1705-03	8.7985-04	1.3643-03	3.8432-02	1.0134+00
3.8000-02	5.4868-01	4.6082+03	5.0735+04	4.5146-02	4.3327+02	2.6253+06	1.7654-03	-1.1089-03	3.8096-02
3.7729+00	2.3514-03	9.8965+07	3.2107-03	1.9000+03	0.0000	9.0666+06	8.8139-02	3.1838-02	
226.0	1.0159+00	9.2372+03	2.1313+00	1.4765-06	3.1916-03	8.8763-04	1.3544-03	3.8827-02	1.0146+00
4.0000-02	5.5041-01	4.6035+03	5.0155+04	3.8749-02	4.3262+02	2.6240+06	1.7919-03	1.6812-01	4.0101-02
3.7752+00	2.3441-03	9.8868+07	3.1772-03	1.9000+03	0.0000	9.0703+06	8.8169-02	4.6486+00	
227.0	1.0171+00	9.2512+03	2.1359+00	1.4754-06	3.2837-03	9.1331-04	1.3732-03	3.9385-02	1.0158+00
4.2000-02	5.4973-01	4.5975+03	4.9775+04	3.3885-02	4.4446+02	2.6870+06	1.7932-03	2.3798-01	4.2106-02
3.7776+00	2.3466-03	9.8738+07	3.1573-03	1.9000+03	0.0000	9.0740+06	8.8196-02	5.9505+00	
228.0	1.0183+00	9.2606+03	2.1390+00	1.4747-06	3.2562-03	9.1531-04	1.3823-03	3.9721-02	1.0170+00
4.400 -02	5.4944-01	4.5934+03	4.9536+04	3.2123-02	4.3911+02	2.6851+06	1.7958-03	1.4326+01	4.4111-02
3.779 .00	2.3456-03	9.8651+07	3.1450-03	1.9000+03	0.0000	9.0777+06	8.8222-02	4.0112+00	
229.0	1.0195+00	9.2682+03	2.1415+00	1.4742-06	3.2779-03	9.2335-04	1.3859-03	3.9828-02	1.0182+00
4.6000-02	5.4889-01	4.5902+03	4.9303+04	3.1927-02	4.4099+02	2.7001+06	1.8028-03	4.5769-02	4.6116-02
3.7823+00	2.3452-03	9.8581+07	3.1324-03	1.9000+03	0.0000	9.0815+06	8.8247-02	3.2480+00	
230.0	1.0208+00	9.2733+03	2.1432+00	1.4738-06	3.2273-03	9.2066-04	1.3908-03	3.9830-02	1.0194+00
4.8000-02	5.4921-01	4.5879+03	4.9135+04	3.1732-02	4.3339+02	2.6858+06	1.8076-03	6.9638-04	4.8121-02
3.7846+00	2.3444-03	9.8533+07	3.1232-03	1.9000+03	0.0000	9.0853+06	8.8273-02	2.1784+00	
231.0	1.0220+00	9.2751+03	2.1438+00	1.4736-06	3.2349-03	9.2562-04	1.3970-03	3.9780-02	1.0207+00
5.0000-02	5.4954-01	4.5872+03	4.9096+04	3.1537-02	4.3430+02	2.6991+06	1.8063-03	-2.1305-02	5.0126-02
3.7870+00	2.3448-03	9.8517+07	3.1212-03	1.9000+03	0.0000	9.0890+06	8.8298-02	7.3620-01	
232.0	1.0232+00	9.2733+03	2.1432+00	1.4738-06	3.1854-03	9.2359-04	1.4017-03	3.9642-02	1.0219+00
5.2000-02	5.4980-01	4.5880+03	4.9237+04	3.1342-02	4.2865+02	2.6999+06	1.7984-03	-5.8698-02	5.2131-02
3.7893+00	2.3453-03	9.8534+07	3.1297-03	1.9000+03	0.0000	9.0928+06	8.8323-02	-7.4698-01	

THROAT RADIUS CORRECTED FOR DISPLACEMENT THICKNESS = 3.0425809-01

EQUILIBRIUM SAMPLE CASE

EQUILIBRIUM TEST CASE

FLAGS AND OPTIONS

IDEAL =	0	(=1 FOR PERFECT GAS, =0 FOR HYDROGEN-OXYGEN EQUILIBRIUM)
LAMNR =	0	(=1 FOR LAMINAR FLOW, =0 FOR TURBULENT)
INCOMP=	0	(=1 FOR INCOMPRESSIBLE FLOW, =0 FOR COMPRESSIBLE)
J2D =	1	(=1 FOR AXISYMMETRIC GEOMETRY, =0 FOR TWO-DIMENSIONAL)
INTDK =	1	(=1 IF INPUT TABLES COME FROM TDK OUTPUT, =0 OTHERWISE)

PROBLEM LIMITS AND INITIAL VALUES

SINIT = 0.0000000 XINIT = -3.5516000+00 XMAX = +3.5448903+00 DX = 6.5499999-05
DELTAI= 4.9999999-04 ZETAPI= 0.0000000

REFERENCE QUANTITIES

BLREF = 3.0502500-01 UREF = 1.0000000+03 RHOREF= 3.0000000-03 SMUREF= 5.0000000-07

INPUT NORMALIZATION FACTORS

XN = 3.0502500-01 YN = 1.0000000+00 UEN = 1.0000000+00 PEN = 4.4593800+05 SMDN = 1.1190000+00

EDGE QUANTITIES

UEDGE = 0.0000000 PEDGE = 1.0000000+00 TEDGE = 6.6500000+03 AFEDGE= 1.3717000-01

CONSTANTS

AFTRNS= 9.9990000-01 PRI = 0.0000000 GAMMA = 0.0000000 FMOLWT= 0.0000000 PLAW = 7.0000000+00
PAMB = 0.0000000 GPO = 1.0000000+03 SN3 = 4.0000001+00 XSTAR = 0.0000000 AFWALL= 9.5999999-01
UEK = 0.0000000 RHOEK = 0.0000000

CONVERGENCE AND EDGE CRITERIA

CONVRG= 4.9999999-03 EPSLN1= 9.9999999-02 EPSLN2= 9.9999999-02 EPSLN3= 9.9999999-02

COUNTERS

MAXIT = 1 NYI = 120 NLPRNT= 20 NSPRNT= 20 IYPR = 1
IYEQ = 8

TEPSIZE CONTROL TABLES

LDXLIM= 8

DXLIM	XLIM
2.5000000-02	-3.1407530+00
1.5000000-02	-5.0000000-01
2.0000000-03	-5.0000000-02
9.9999999-05	0.0000000
2.0000000-03	2.0000000-03
9.9999999-05	1.9120000+00
2.0000000-01	3.0100000+00
2.0000000-01	2.2000000+01

LSKTAB= 7

SKTAB	XTABSK
1.1500000+00	-3.5015500+00
1.0500000+00	-3.1407501+00
1.0000000+00	5.2000000-02
1.1000000+00	2.4869412-01
1.0100000+00	1.9120000+00
1.1500000+00	3.0100000+00
1.0000000+00	2.2000000+01

WALL TABLES

LTWTAB= 12

TWTAB	XTABTW
1.4000000+03	-3.5516000+00
1.4000000+03	-1.9120000+00
1.3000000+03	-1.3660000+00
1.3000000+03	0.0000000
1.4000000+03	0.0000000
1.4000000+03	1.9120000+00
1.3000000+03	1.9120000+00
1.2000000+03	3.0050000+00
1.0000000+03	4.1000000+00
9.5000000+02	6.8300000+00
1.0600000+03	8.4700000+00
1.5000000+03	2.1390000+01

LMDTAB= 27

SMDTAB	XTABMD
6.6000000-03	-3.5516000+00
6.6000000-03	-3.4150000+00
6.6000000-03	-3.1420000+00
6.6000000-03	-2.8690000+00
7.3000000-03	-2.5950000+00
4.8000000-03	-2.3220000+00
4.8000000-03	-2.0490000+00
5.9000000-03	-1.7760000+00
4.8000000-03	-1.5030000+00
6.6999999-03	-1.2290000+00
8.9999999-03	-9.9699999-01
1.3600000-02	-7.3300000-01
1.4800000-02	-4.9700000-01
2.2600000-02	-3.5999999-01
2.7600000-02	-4.2300000-01
3.9700000-02	-2.8700000-01
3.6600000-02	0.0000000
7.2200000-03	4.1000000-02
5.1299999-03	1.3700000-01
9.5999999-03	2.6000000-01
4.8800000-03	3.5500000-01
2.2500000-03	5.4600000-01
2.3300000-03	8.0599999-01
1.5700000-03	1.1340000+00
7.9999999-04	1.5850000+00
0.0000000	1.8300000+00
0.0000000	2.2000000+01

```
THERMO DRUM
 EACTANTS
    2.0000      -.0000      -.0000      -.0000      -.0000  100.0000          .00  G   298.15  F     -.0000
    2.0000      -.0000      -.0000      -.0000      -.0000  100.0000          .00  G   298.15  O     -.0000
 O INPT2 VALUE GIVEN FOR OF, EQRAT, FA, OR FPCT

                  FUEL              OXIDANT             MIXTURE

 .CAL/G        .00000000          .00000000          .00000000
 +             .99206350-00       .00000000          .49603175-00
 -             .00000000         -.12500000-00      -.62500000-01
 TOMS/G
               .99206350-00       .00000000          .49603175-00
               .00000000          .62500000-01       .31250000-01

PECIES BEING CONSIDERED IN THIS SYSTEM
   J 9/65  H                 J 3/61  H2                J 3/61  H20               J 6/62  O                 J 3/66  OH
   J 9/65  O2
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.377228-00	.413012-00	.488972-00	.105301+01	.106759+01	.107420+01	.108560+01	.110255+01
.112484+01	.115393+01	.119067+01	.123650+01	.129335+01	.136362+01	.145134+01	.156239+01
.170540+01	.189601+01	.215414+01	.244290+01	.274405+01	.305801+01	.338452+01	.372300+01
.407247+01	.445469+01	.484676+01	.529796+01	.599017+01	.604593+01	.620955+01	.636179+01
.652617+01	.667421+01	.683096+01	.698330+01	.713519+01	.728701+01	.743892+01	.759130+01
.774440+01	.789845+01	.805364+01	.821040+01	.836884+01	.852924+01	.869199+01	.885720+01
.902533+01	.919671+01	.937168+01	.949211+01	.948964+01	.948658+01	.948396+01	.948110+01
.947803+01	.947484+01	.947169+01	.946864+01	.949366+01	.951201+01	.952968+01	.951433+01
.953824+01	.954682+01	.957279+01	.959194+01	.963354+01	.968670+01	.974074+01	.980204+01
.985513+01	.990898+01	.998116+01	.100463+02	.101097+02	.101731+02	.102346+02	.103074+02
.103765+02	.104498+02	.105234+02	.105992+02	.106770+02	.107551+02	.108357+02	.109136+02
.109837+02	.110523+02	.111430+02	.111886+02	.112507+02	.112929+02	.113866+02	.114055+02
.114719+02	.115183+02	.115696+02	.116347+02	.117801+02	.118837+02	.119976+02	.121187+02
.122319+02	.123495+02	.124891+02	.126112+02	.127459+02	.128701+02	.130114+02	.131544+02
.132217+02	.132766+02	.133511+02	.134329+02	.134963+02	.135539+02	.136172+02	.136819+02
.137428+02	.138043+02	.138347+02	.138604+02	.138836+02	.139042+02	.139252+02	.139437+02
.139634+02	.139807+02	.139941+02	.140063+02	.140195+02			
-.355160+01	-.300500+01	-.245900+01	-.187192+01	-.180860+01	-.173067+01	-.165274+01	-.157481+01
-.149688+01	-.141895+01	-.134102+01	-.126308+01	-.118515+01	-.110722+01	-.102929+01	-.951363-00
-.873432-00	-.795502-00	-.717571-00	-.639641-00	-.561710-00	-.483780-00	-.405849-00	-.327919-00
-.249988-00	-.167187-00	-.843858-01	-.357650-01	-.363261-02	.000000	.947994-03	.192875-02
.293849-02	.397025-02	.503324-02	.612121-02	.723291-02	.836758-02	.952488-02	.107047-01
.119067-01	.131306-01	.143765-01	.156445-01	.169345-01	.182466-01	.195810-01	.209378-01
.223171-01	.237191-01	.251440-01	.266007-01	.280562-01	.294914-01	.309300-01	.323697-01
.338048-01	.352355-01	.366622-01	.380878-01	.403695-01	.437150-01	.487323-01	.558642-01
.670349-01	.833879-01	.107911+00	.143987-00	.197421-00	.269520-00	.340154-00	.409749-00
.477968-00	.545380-00	.613299-00	.680990-00	.748172-00	.815119-00	.881601-00	.950998-00
.101981+01	.109017+01	.116094+01	.123301+01	.130588+01	.138020+01	.145511+01	.153175+01
.160784+01	.168542+01	.177762+01	.185629+01	.194111+01	.202597+01	.213574+01	.220428+01
.230881+01	.239746+01	.249988+01	.261859+01	.290300+01	.313795+01	.344146+01	.374948+01
.412420+01	.451557+01	.499618+01	.552411+01	.614882+01	.683468+01	.765933+01	.858835+01
.909825+01	.964145+01	.102824+02	.109974+02	.116880+02	.123959+02	.131751+02	.140095+02
.149125+02	.158191+02	.163154+02	.168028+02	.172957+02	.177878+02	.183079+02	.188294+02
.193873+02	.199495+02	.204970+02	.210580+02	.213908+02			

EQUILIBRIUM TEST CASE

STATION	X	S	DS	RW	THETAW	ZETA	ZETAP
0	-3.5516000+00	0.0000000	6.5499999-05	1.7227900+00	0.0000000	1.3660082-03	3.[illegible]-02

EDGE AND WALL CONDITIONS

UE =	.3772285+03	ME =	.7262565-01		
TE =	.6647880+04	RHOE =	.1884808-01		
HE =	-.7968727+07	MUE =	.2117189-05		
PE =	.4446301+06	TW =	.1400000+04		
		MDOTW =	.0000000		

PROFILE PARAMETERS

DELTA* =	.1353381-03	CF =	.1372945-02
THETA =	.3189647-04	ST =	.1011224-02
TAUW =	.1841192+01		
QW =	-.5282559+06		

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
1	0.0000000	-0.0000000	0.0000000	-8.2290472+00	7.1139076-01	1.8021854+00	0.0000000	1400.0
2	4.4802745-09	9.2455547-03	6.2901413-05	-8.2284673+00	7.1139459-01	1.8021943+00	7.6749931-16	1399.9
3	1.0078445-08	1.8491109-02	1.4599036-04	-8.2277012+00	7.1139193-01	1.8022061+00	2.6735604-13	1400.0
4	1.8030040-08	2.7736664-02	2.5313516-04	-8.2267133+00	7.1138281-01	1.8022214+00	1.2053805-12	1400.1
5	2.7677740-08	3.6982219-02	3.8858534-04	-8.2254644+00	7.1136720-01	1.8022407+00	4.5071601-12	1400.3
6	3.9668914-08	4.6227773-02	5.5693703-04	-8.2239123+00	7.1134512-01	1.8022646+00	1.4716925-11	1400.6
7	5.4355653-08	5.5473328-02	7.6313347-04	-8.2220110+00	7.1131656-01	1.8022940+00	4.3304865-11	1400.9
8	7.2114803-08	6.4718882-02	1.0124654-03	-8.2197123+00	7.1128151-01	1.8023295+00	1.1724584-10	1401.4
9	9.3348079-08	7.3964437-02	1.3105719-03	-8.2169636+00	7.1123999-01	1.8023720+00	2.9637622-10	1401.9
10	1.1848177-07	8.3209991-02	1.6634406-03	-8.2137101+00	7.1119300-01	1.8024223+00	7.0496713-10	1402.5
11	1.4796750-07	9.2455546-02	2.0774095-03	-8.2098933+00	7.1114383-01	1.8024812+00	1.6041818-09	1403.1
12	1.8228159-07	1.0170110-01	2.5591668-03	-8.2054514+00	7.1109257-01	1.8025499+00	3.4842619-09	1403.7
13	2.2192553-07	1.1094666-01	3.1157533-03	-8.2003196+00	7.1103610-01	1.8026292+00	7.2796903-09	1404.4
14	2.6742599-07	1.2019221-01	3.7545630-03	-8.1944297+00	7.1096979-01	1.8027202+00	1.4689673-08	1405.2
15	3.1933492-07	1.2943777-01	4.4833453-03	-8.1877100+00	7.1088897-01	1.8028240+00	2.8725387-08	1406.2
16	3.7822970-07	1.3868332-01	5.3102065-03	-8.1800862+00	7.1079054-01	1.8029418+00	5.4592787-08	1407.5
17	4.4471333-07	1.4792888-01	6.2436123-03	-8.1714802+00	7.1067460-01	1.8030747+00	1.0109171-07	1409.0
18	5.1941452-07	1.5717443-01	7.2923898-03	-8.1618102+00	7.1054570-01	1.8032241+00	1.8278402-07	1410.6
19	6.0298801-07	1.6641998-01	8.4657309-03	-8.1509916+00	7.1040912-01	1.8033913+00	3.2328513-07	1412.3
20	6.9611468-07	1.7566554-01	9.7731952-03	-8.1389364+00	7.1026488-01	1.8035775+00	5.6017088-07	1414.1
21	7.9950183-07	1.8491109-01	1.1224713-02	-8.1255531+00	7.1010909-01	1.8037843+00	9.5215766-07	1416.1
22	9.1388348-07	1.9415665-01	1.2830590-02	-8.1107463+00	7.0993574-01	1.8040131+00	1.5894656-06	1418.3
23	1.0400207-06	2.0340221-01	1.4601511-02	-8.0944178+00	7.0973888-01	1.8042654+00	2.6086263-06	1420.8
24	1.1787020-06	2.1264776-01	1.6548545-02	-8.0764653+00	7.0951454-01	1.8045427+00	4.2135566-06	1423.7
25	1.3307434-06	2.2189331-01	1.8683151-02	-8.0567832+00	7.0926286-01	1.8048468+00	6.7051780-06	1427.1
26	1.4969893-06	2.3113887-01	2.1017182-02	-8.0352625+00	7.0898938-01	1.8051793+00	1.0521834-05	1430.7
27	1.6783126-06	2.4038442-01	2.3562895-02	-8.0117897+00	7.0869984-01	1.8055419+00	1.6293465-05	1434.5
28	1.8756154-06	2.4962997-01	2.6332954-02	-7.9862481+00	7.0839437-01	1.8059365+00	2.4913298-05	1438.5
29	2.0898294-06	2.5887553-01	2.9340439-02	-7.9585173+00	7.0806877-01	1.8063650+00	3.7431208-05	1442.7
30	2.3219164-06	2.6812109-01	3.2598858-02	-7.9284725+00	7.0771676-01	1.8068291+00	5.6174945-05	1447.3
31	2.5728697-06	2.7736664-01	3.6122149-02	-7.8959852+00	7.0733199-01	1.8073310+00	8.2909239-05	1452.6
32	2.8437136-06	2.8661220-01	3.9924698-02	-7.8609226+00	7.0691030-01	1.8078727+00	1.2105014-04	1458.5
33	3.1355050-06	2.9585775-01	4.4021343-02	-7.8231479+00	7.0645180-01	1.8084563+00	1.7494795-04	1465.1
34	3.4493340-06	3.0510330-01	4.8427387-02	-7.7825202+00	7.0596178-01	1.8090840+00	2.5042666-04	1472.2
35	3.7863249-06	3.1434886-01	5.3158616-02	-7.7388933+00	7.0544435-01	1.8097580+00	3.5518166-04	1479.5
36	4.1476371-06	3.2359441-01	5.8[illegible]96-02	-7.6921175+00	7.0489959-01	1.8104806+00	4.9925143-04	1487.2
37	4.5344659-06	3.3283997-01	6[illegible]1-02	-7.6420377+00	7.0432492-01	1.8112542+00	6.9554467-04	1495.3
38	4.9480443-06	3.4208553-01	6[illegible]5-02	-7.5884943+00	7.0371643-01	1.8120814+00	9.6047245-04	1504.1
39	5.3896432-06	3.5133108-01	7.[illegible]618-02	-7.5313225+00	7.0307020-01	1.8129646+00	1.3147786-03	1513.9
40	5.8605736-06	3.6057663-01	8.2280308-02	-7.4703526+00	7.0238367-01	1.8139065+00	1.7847720-03	1524.9
41	6.3621877-06	3.6982219-01	8.9322788-02	-7.4054094+00	7.0165692-01	1.8149097+00	2.4039807-03	1537.1
42	6.8958804-06	3.7906774-01	9.6815637-02	-7.3363120+00	7.0089109-01	1.8159771+00	3.2145748-03	1550.1
43	7.4630903-06	3.8831329-01	1.0477906-01	-7.2628739+00	7.0008201-01	1.8171115+00	4.2685692-03	1563.6
44	8.0653027-06	3.9755885-01	1.1323390-01	-7.1849028+00	6.9922957-01	1.8183159+00	5.6287342-03	1577.4
45	8.7040505-06	4.0680441-01	1.2220168-01	-7.1021999+00	6.9833848-01	1.8195934+00	7.3691250-03	1592.0

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	RCJ	EPS	T
46	9.3809158-06	4.1604996-01	1.3170463-01	-7.0145602+00	6.9741593-01	1.8229471+00	9.5756679-03	1608.0
47	1.0097534-05	4.2529552-01	1.4176568-01	-6.9217715+00	6.9446913-01	1.8223804+00	1.2348446-02	1625.7
48	1.0855592-05	4.3454107-01	1.5240854-01	-6.8236151+00	6.9550279-01	1.8238965+00	1.5408335-02	1645.8
49	1.1656836-05	4.4378663-01	1.6365772-01	-6.7198646+00	6.9451683-01	1.8254990+00	2.0107354-02	1668.0
50	1.2503070-05	4.5303218-01	1.7553852-01	-6.6102862+00	6.9349434-01	1.8271914+00	2.5429840-02	1691.8
51	1.3396159-05	4.6227773-01	1.8807717-01	-6.4946376+00	6.9239553-01	1.8289776+00	3.1987115-02	1716.0
52	1.4338035-05	4.7152329-01	2.0130076-01	-6.3726686+00	6.9121948-01	1.8308614+00	4.0006638-02	1740.7
53	1.5330694-05	4.8076884-01	2.1523733-01	-6.2441199+00	6.9000211-01	1.8328447+00	4.9715884-02	1766.7
54	1.6376207-05	4.9001440-01	2.2991595-01	-6.1087230+00	6.8879781-01	1.8349377+00	6.1328428-02	1795.4
55	1.7476717-05	4.9925996-01	2.4536671-01	-5.9661995+00	6.8766092-01	1.8371387+00	7.5055618-02	1828.1
56	1.8634445-05	5.0850550-01	2.6162079-01	-5.8162614+00	6.8662737-01	1.8394547+00	9.1174835-02	1865.8
57	1.9851698-05	5.1775106-01	2.7871057-01	-5.6586093+00	6.8569628-01	1.8418877+00	1.1014229-01	1908.3
58	2.1130863-05	5.2699661-01	2.9666959-01	-5.4929328+00	6.8477228-01	1.8444470+00	1.3253989-01	1953.8
59	2.2474423-05	5.3624216-01	3.1553268-01	-5.3189097+00	6.8365896-01	1.8471342+00	1.5894181-01	1998.6
60	2.3884957-05	5.4548772-01	3.3533606-01	-5.1362050+00	6.8235185-01	1.8499552+00	1.8974005-01	2042.7
61	2.5365140-05	5.5473328-01	3.5611729-01	-4.9444713+00	6.8102445-01	1.8529156+00	2.2494985-01	2089.1
62	2.6917759-05	5.6397883-01	3.7791548-01	-4.7433466+00	6.7993923-01	1.8560208+00	2.6409493-01	2142.5
63	2.8545709-05	5.7322439-01	4.0077130-01	-4.5324543+00	6.7935861-01	1.8592767+00	3.0446119-01	2207.8
64	3.0252004-05	5.8246994-01	4.2472705-01	-4.3114029+00	6.7945612-01	1.8626893+00	3.5130529-01	2287.9
65	3.2039784-05	5.9171550-01	4.4982684-01	-4.0797839+00	6.8022729-01	1.8662649+00	3.9734016-01	2382.9
66	3.3912319-05	6.0096105-01	4.7611655-01	-3.8371724+00	6.8155351-01	1.8700100+00	4.4349953-01	2492.2
67	3.5873020-05	6.1020660-01	5.0364406-01	-3.5831247+00	6.8359102-01	1.8739314+00	4.8975974-01	2624.6
68	3.7925443-05	6.1945216-01	5.3245934-01	-3.3171777+00	6.8634499-01	1.8780362+00	5.3738132-01	2780.2
69	4.0073301-05	6.2869772-01	5.6261448-01	-3.0388489+00	6.8961491-01	1.8823319+00	5.8894303-01	2950.0
70	4.2320471-05	6.3794327-01	5.9416391-01	-2.7476335+00	6.9309743-01	1.8868263+00	6.4887749-01	3120.5
71	4.4671004-05	6.4718883-01	6.2716454-01	-2.4430039+00	6.9648921-01	1.8915273+00	7.2234056-01	3278.0
72	4.7129133-05	6.5643438-01	6.6167577-01	-2.1244092+00	6.9958971-01	1.8964436+00	7.2245917-01	3413.6
73	4.9699290-05	6.6567993-01	6.9775983-01	-1.7912718+00	7.0240413-01	1.9015839+00	6.2836127-01	3527.5
74	5.2386112-05	6.7492549-01	7.3548184-01	-1.442 [illegible]7+00	7.0515033-01	1.9069576+00	5.2444711-01	3628.3
75	5.5194452-05	6.8417104-01	7.4098915-01	-1.3921[illegible]1+00	7.0790908-01	1.9125742+00	4.0726275-01	3715.7
76	5.8129402-05	6.9341660-01	7.4649379-01	-1.3413106+00	7.1068072-01	1.9184441+00	2.7279259-01	3789.6
77	6.1196294-05	7.0266216-01	7.5199698-01	-1.2904968+00	7.1345139-01	1.9245779+00	2.0807792-01	3853.0
78	6.4400723-05	7.1190771-01	7.5749996-01	-1.2396846+00	7.1620012-01	1.9309868+00	2.3306325-01	3910.6
79	6.7748563-05	7.2115326-01	7.6300398-01	-1.1888621+00	7.1890597-01	1.9376825+00	2.6113217-01	3967.0
80	7.1245986-05	7.3039882-01	7.6851032-01	-1.1380177+00	7.2155508-01	1.9446773+00	2.9249018-01	4025.2
81	7.4899470-05	7.3964437-01	7.7402025-01	-1.0871395+00	7.2414780-01	1.9519843+00	3.2753082-01	4085.2
82	7.8715828-05	7.4888992-01	7.7953506-01	-1.0362159+00	7.2667247-01	1.9596170+00	3.6680147-01	4143.1
83	8.2702236-05	7.5813548-01	7.8505608-01	-9.8523423-01	7.2904836-01	1.9675898+00	4.1094118-01	4196.2
84	8.6866229-05	7.6738103-01	7.9058462-01	-9.3418274-01	7.3127337-01	1.9759178+00	4.6057069-01	4244.4
85	9.1215761-05	7.7662659-01	7.9612201-01	-8.8304883-01	7.3342771-01	1.9846169+00	5.1614925-01	4289.4
86	9.5759206-05	7.8587215-01	8.0166963-01	-8.3182005-01	7.3563270-01	1.9937038+00	5.7797498-01	4333.7
87	1.0050538-04	7.9511770-01	8.0722889-01	-7.8048319-01	7.3800965-01	2.0031961+00	6.4631631-01	4380.0
88	1.0546361-04	8.0436325-01	8.1280115-01	-7.2902556-01	7.4063872-01	2.0131126+00	7.2158099-01	4429.9
89	1.1064373-04	8.1360881-01	8.1838789-01	-6.7743384-01	7.4351791-01	2.0234728+00	8.0432546-01	4483.4
90	1.1605610-04	8.2285436-01	8.2399051-01	-6.2569485-01	7.4654477-01	2.0342976+00	8.9526137-01	4538.6
91	1.2171170-04	8.3209991-01	8.2961054-01	-5.7379454-01	7.4963783-01	2.0456088+00	9.9525319-01	4594.8
92	1.2762213-04	8.4134547-01	8.3524948-01	-5.2171903-01	7.5279576-01	2.0574296+00	1.1052596+00	4652.1
93	1.3379964-04	8.5059103-01	8.4090886-01	-4.6945415-01	7.5607034-01	2.0697846+00	1.2262132+00	4710.5
94	1.4025723-04	8.5983658-01	8.4659024-01	-4.1698551-01	7.5953998-01	2.0826998+00	1.3591145+00	4770.3
95	1.4700866-04	8.6908214-01	8.5229523-01	-3.6429837-01	7.6328307-01	2.0962027+00	1.5050339+00	4831.6
96	1.5406846-04	.7832769-01	8.5802548-01	-3.1137723-01	7.6735140-01	2.1103223+00	1.6651327+00	4894.7
97	1.6145212-04	..8757325-01	8.6378264-01	-2.5820702-01	7.7174366-01	2.1250896+00	1.8406316+00	4959.5
98	1.6917600-04	8.9681880-01	8.6956841-01	-2.0477200-01	7.7636373-01	2.1405374+00	2.0328490+00	5025.9
99	1.7725750-04	9.0606435-01	8.7538455-01	-1.5105586-01	7.8106207-01	2.1567004+00	2.2177728+00	5093.8
100	1.8571509-04	9.1530991-01	8.8123285-01	-9.7042163-02	7.8583549-01	2.1735156+00	2.3809477+00	5163.3
101	1.9456841-04	9.2455547-01	8.8711511-01	-4.2714128-02	7.9080851-01	2.1913222+00	2.4570920+00	5234.2
102	2.0383830-04	9.3380102-01	8.9303323-01	1.1945644-02	7.9616947-01	2.2098620+00	2.5002250+00	5306.8

NO.	YRAR	Y	U/UF	H/HE	RO/ROE	ROV	EPS	T
103	2.1334699-04	9.4304658-01	8.9898910-01	6.6954789-02	8.0210678-01	2.2292774+00	2.4835734+00	5380.7
104	2.2371811-04	9.5229213-01	9.0498470-01	1.2233142-01	8.0874496-01	2.2496216+00	2.4949832+00	5456.0
105	2.3437681-04	9.6153768-01	9.1102204-01	1.7809437-01	8.1608070-01	2.2709371+00	2.3529747+00	5532.7
106	2.4554995-04	9.7078324-01	9.1710316-01	2.3426237-01	8.2399430-01	2.2932854+00	2.2627683+00	5611.2
107	2.5726611-04	9.8002879-01	9.2323023-01	2.9085532-01	8.3248579-01	2.3167177+00	2.1954324+00	5694.9
108	2.6955584-04	9.8927435-01	9.2940538-01	3.4789301-01	8.4155615-01	2.3412970+00	2.0292787+00	5782.7
109	2.8245172-04	9.9851990-01	9.3563086-01	4.0539635-01	8.5116682-01	2.3670439+00	1.8447747+00	5872.9
110	2.9598857-04	1.0077655+00	9.4190894-01	4.6338631-01	8.6125951-01	2.3941626+00	1.7239591+00	5962.2
111	3.1020360-04	1.0170110+00	9.4824201-01	5.2188472-01	8.7177587-01	2.4225926+00	1.5505439+00	6047.2
112	3.2513665-04	1.0262566+00	9.5463248-01	5.8091430-01	8.8267745-01	2.4524587+00	1.3497076+00	6125.7
113	3.4083034-04	1.0355021+00	9.6108285-01	6.4049771-01	8.9396517-01	2.4838441+00	1.1875697+00	6197.8
114	3.5733026-04	1.0447477+00	9.6759564-01	7.0065869-01	9.0568004-01	2.5168440+00	1.0104423+00	6265.8
115	3.7468539-04	1.0539932+00	9.7417354-01	7.6142163-01	9.1783477-01	2.5515542+00	8.4403064-01	6330.4
116	3.9294817-04	1.0632388+00	9.8081922-01	8.2281160-01	9.3042936-01	2.5880818+00	6.9277668-01	6391.7
117	4.1217484-04	1.0724843+00	9.8753550-01	8.8485454-01	9.4346377-01	2.6265351+00	5.5948755-01	6449.7
118	4.3242593-04	1.0817299+00	9.9432524-01	9.4757695-01	9.5693806-01	2.6670373+00	4.4529296-01	6504.3
119	4.5375637-04	1.0909754+00	1.0000000+00	1.0000000+00	9.7085220-01	2.7097182+00	3.4987621-01	6555.5
120	4.7[illegible]84-04	1.1002210+00	1.0000000+00	1.0000000+00	9.8520616-01	2.7547174+00	2.5433201-01	6603.7
121	4.9[illegible]90-04	1.1094666+00	1.0000000+00	1.0000000+00	1.0.00000+00	2.8021853+00	1.9419612-01	6647.9

EQUILIBRIUM TEST CASE

NO.	YBAR	O/F	C(H)	C(H2)	C(H2O)	C(O)	C(OH)	C(O2)	MU	PR
1	0.0000000	4.1466674-02	.000000	.954960	.045040	.000000	.000000	.000000	3.55844-07	.67879
2	4.4802745-09	4.1722831-02	.000000	.000000	.000000	.000000	.000000	.000000	3.55851-07	.67880
3	1.0398445-08	4.1797026-02	.000000	.000000	.000000	.000000	.000000	.000000	3.55859-07	.67879
4	1.8030040-08	4.1892730-02	.000000	.000000	.000000	.000000	.000000	.000000	3.55886-07	.67877
5	2.7677740-08	4.2013723-02	.000000	.000000	.000000	.000000	.000000	.000000	3.55934-07	.67874
6	3.9668914-08	4.2164166-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56003-07	.67870
7	5.4355653-08	4.2348473-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56091-07	.67864
8	7.2114803-08	4.2571424-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56200-07	.67857
9	9.3348609-08	4.2838109-02	.000000	.953746	.046254	.000000	.000000	.000000	3.56329-07	.67849
10	1.1848177-07	4.3153962-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56475-07	.67839
11	1.4796750-07	4.3524753-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56627-07	.67829
12	1.8228159-07	4.3956590-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56784-07	.67819
13	2.2192553-07	4.4455948-02	.000000	.000000	.000000	.000000	.000000	.000000	3.56957-07	.67808
14	2.6742599-07	4.5029674-02	.000000	.000000	.000000	.000000	.000000	.000000	3.57162-07	.67794
15	3.1933492-07	4.5684975-02	.000000	.000000	.000000	.000000	.000000	.000000	3.57414-07	.67778
16	3.7822970-07	4.6429446-02	.000000	.000000	.000000	.000000	.000000	.000000	3.57725-07	.67758
17	4.4471333-07	4.7271132-02	.000000	.949175	.050825	.000000	.000000	.000000	3.58094-07	.67735
18	5.1941452-07	4.8218475-02	.000000	.000000	.000000	.000000	.000000	.000000	3.58524-07	.67709
19	6.0298801-07	4.9280362-02	.000000	.000000	.000000	.000000	.000000	.000000	3.58935-07	.67682
20	6.9611468-07	5.0466165-02	.000000	.000000	.000000	.000000	.000000	.000000	3.59387-07	.67653
21	7.9950183-07	5.1785770-02	.000000	.000000	.000000	.000000	.000000	.000000	3.59875-07	.67622
22	9.1388348-07	5.3249564-02	.000000	.000000	.000000	.000000	.000000	.000000	3.60424-07	.67587
23	1.0400207-06	5.4868537-02	.000000	.000000	.000000	.000000	.000000	.000000	3.61058-07	.67547
24	1.1787020-06	5.6654253-02	.000000	.000000	.000000	.000000	.000000	.000000	3.61793-07	.67502
25	1.3307434-06	5.8618969-02	.000000	.937650	.062350	.000000	.000000	.000000	3.62628-07	.67450
26	1.4969893-06	6.0775631-02	.000000	.000000	.000000	.000000	.000000	.000000	3.63558-07	.67395
27	1.6783126-06	6.3137915-02	.000000	.000000	.000000	.000000	.000000	.000000	3.64488-07	.67336
28	1.8756154-06	6.5720359-02	.000000	.000000	.000000	.000000	.000000	.000000	3.65477-07	.67274
29	2.0898294-06	6.8538400-02	.000000	.000000	.000000	.000000	.000000	.000000	3.66533-07	.67209
30	2.3219164-06	7.1608432-02	.000000	.000000	.000000	.000000	.000000	.000000	3.67698-07	.67137
31	2.5728697-06	7.4947948-02	.000000	.000000	.000000	.000000	.000000	.000000	3.69011-07	.67058
32	2.8437136-06	7.8575567-02	.000000	.000000	.000000	.000000	.000000	.000000	3.70502-07	.66972
33	3.1355050-06	8.2511272-02	.000000	.914174	.085826	.000000	.000000	.000000	3.72169-07	.66877
34	3.4493340-06	8.6776392-02	.000000	.000000	.000000	.000000	.000000	.000000	3.73967-07	.66775
35	3.7863249-06	9.1393888-02	.000000	.000000	.000000	.000000	.000000	.000000	3.75830-07	.66668
36	4.1476371-06	9.6388401-02	.000000	.000000	.000000	.000000	.000000	.000000	3.77759-07	.66556
37	4.5344659-06	1.0178657-01	.000000	.000000	.000000	.000000	.000000	.000000	3.79804-07	.66437
38	4.9480443-06	1.0761715-01	.000000	.000000	.000000	.000000	.000000	.000000	3.82044-07	.66311
39	5.3896432-06	1.1391126-01	.000000	.000000	.000000	.000000	.000000	.000000	3.84556-07	.66175
40	5.8605736-06	1.2070273-01	.000000	.000000	.000000	.000000	.000000	.000000	3.87393-07	.66029
41	6.3621877-06	1.2802838-01	.000000	.872202	.127798	.000000	.000000	.000000	3.90552-07	.65871
42	6.8958804-06	1.3592839-01	.000000	.000000	.000000	.000000	.000000	.000000	3.93944-07	.65705
43	7.4630903-06	1.4444675-01	.000000	.000000	.000000	.000000	.000000	.000000	3.97435-07	.65531
44	8.0653027-06	1.5363175-01	.000000	.000000	.000000	.000000	.000000	.000000	4.01021-07	.65348
45	8.7040505-06	1.6353647-01	.000000	.000000	.000000	.000000	.000000	.000000	4.04813-07	.65157
46	9.3809158-06	1.7421956-01	.000000	.000000	.000000	.000000	.000000	.000000	4.08975-07	.64956
47	1.0097534-05	1.8574598-01	.000000	.000000	.000000	.000000	.000000	.000000	4.13674-07	.64744
48	1.0855592-05	1.9818786-01	.000000	.000000	.000000	.000000	.000000	.000000	4.19018-07	.64519
49	1.1656836-05	2.1162552-01	.000000	.803330	.196670	.000000	.000000	.000000	4.25005-07	.64282
50	1.2503070-05	2.2614890-01	.000000	.000000	.000000	.000000	.000000	.000000	4.31422-07	.64033
51	1.3396159-05	2.4185892-01	.000000	.000000	.000000	.000000	.000000	.000000	4.37918-07	.63774
52	1.4338035-05	2.5886922-01	.000000	.000000	.000000	.000000	.000000	.000000	4.44487-07	.63505
53	1.5330694-05	2.7730843-01	.000000	.000000	.000000	.000000	.000000	.000000	4.51423-07	.63225
54	1.6376207-05	2.9732268-01	.000000	.000000	.000000	.000000	.000000	.000000	4.59171-07	.62933
55	1.7476717-05	3.1907865-01	.000000	.000000	.000000	.000000	.000000	.000000	4.68179-07	.62629

NO.	YRAR	O/F	C(H)	C(H2)	C(H2O)	C(O)	C(OH)	C(O2)	MU	PR
56	1.8634445-05	3.4276751-01	.000000	.000000	.000000	.000000	.000000	.000000	4.78740-07	.62313
57	1.9851698-05	3.6860956-01	.000000	.696733	.303267	.000000	.000000	.000000	4.90846-07	.61984
58	2.1130863-05	3.9685999-01	.000000	.000000	.000000	.000000	.000000	.000000	5.03817-07	.61643
59	2.2474403-05	4.2781623-01	.000000	.000000	.000000	.000000	.000000	.000000	5.16343-07	.61288
60	2.3884957-05	4.6182710-01	.000000	.000000	.000000	.000000	.000000	.000000	5.28857-07	.60918
61	2.5365140-05	4.9930431-01	.000000	.000000	.000000	.000000	.000000	.000000	5.41217-07	.60535
62	2.6917759-05	5.4073755-01	.000000	.000000	.000000	.000000	.000000	.000000	5.56337-07	.60143
63	2.8545709-05	5.8671387-01	.000000	.000000	.000000	.000000	.000000	.000000	5.75510-07	.59743
64	3.0252004-05	6.3794304-01	.000000	.000000	.000000	.000000	.000000	.000000	5.99856-07	.59338
65	3.2039784-05	6.9529173-01	.000000	.538192	.461808	.000000	.000000	.000000	6.29345-07	.58929
66	3.3912319-05	7.5982901-01	.000000	.000000	.000000	.000000	.000000	.000000	6.63744-07	.58504
67	3.5873020-05	8.3288972-01	.000000	.000000	.000000	.000000	.000000	.000000	7.05778-07	.58037
68	3.7925443-05	9.1616225-01	.000000	.000000	.000000	.000000	.000000	.000000	7.55523-07	.57529
69	4.0073301-05	1.0118137+00	.000000	.000000	.000000	.000000	.000000	.000000	8.15071-07	.57003
70	4.2320471-05	1.1226731+00	.000000	.000000	.000000	.000000	.000000	.000000	8.85021-07	.56496
71	4.4671004-05	1.2525049+00	.000000	.000000	.000000	.000000	.000000	.000000	9.15974-07	.56043
72	4.7129133-05	1.4064301+00	.000000	.000000	.000000	.000000	.000000	.000000	9.60022-07	.55669
73	4.9699290-05	1.5915982+00	.000015	.308467	.691513	.000000	.000006	.000000	9.97240-07	.55374
74	5.2386112-05	1.8183028+00	.000000	.000000	.000000	.000000	.000000	.000000	1.03043-06	.55137
75	5.5194452-05	1.8547620+00	.000000	.000000	.000000	.000000	.000000	.000000	1.05958-06	.54968
76	5.8129402-05	1.8921585+00	.000000	.000000	.000000	.000000	.000000	.000000	1.08448-06	.54868
77	6.1196294-05	1.9305376+00	.000000	.000000	.000000	.000000	.000000	.000000	1.10662-06	.54819
78	6.4400723-05	1.9699473+00	.000000	.000000	.000000	.000000	.000000	.000000	1.12676-06	.54797
79	6.7748563-05	2.0104393+00	.000000	.000000	.000000	.000000	.000000	.000000	1.14648-06	.54776
80	7.1245986-05	2.0520685+00	.000000	.000000	.000000	.000000	.000000	.000000	1.16666-06	.54739
81	7.4899470-05	2.0948934+00	.000078	.237751	.762097	.000000	.000074	.000000	1.18729-06	.54686
82	7.8715828-05	2.1389767+00	.000000	.000000	.000000	.000000	.000000	.000000	1.20722-06	.54636
83	8.2702236-05	2.1843859+00	.000000	.000000	.000000	.000000	.000000	.000000	1.22553-06	.54595
84	8.6866229-05	2.2311925+00	.000000	.000000	.000000	.000000	.000000	.000000	1.24222-06	.54565
85	9.1215761-05	2.2794743+00	.000000	.000000	.000000	.000000	.000000	.000000	1.25785-06	.54542
86	9.5759206-05	2.3293141+00	.000000	.000000	.000000	.000000	.000000	.000000	1.27331-06	.54527
87	1.0050538-04	2.3808014+00	.000000	.000000	.000000	.000000	.000000	.000000	1.28946-06	.54515
88	1.0546361-04	2.4340327+00	.000000	.000000	.000000	.000000	.000000	.000000	1.30689-06	.54505
89	1.1064373-04	2.4891118+00	.000197	.196540	.802950	.000000	.000313	.000000	1.32558-06	.54499
90	1.1605610-04	2.5461511+00	.000000	.000000	.000000	.000000	.000000	.000000	1.34489-06	.54496
91	1.2171170-04	2.6052723+00	.000000	.000000	.000000	.000000	.000000	.000000	1.36457-06	.54494
92	1.2762213-04	2.6666076+00	.000000	.000000	.000000	.000000	.000000	.000000	1.38443-06	.54495
93	1.3379964-04	2.7302999+00	.000000	.000000	.000000	.000000	.000000	.000000	1.40512-06	.54499
94	1.4025723-04	2.7965052+00	.000000	.000000	.000000	.000000	.000000	.000000	1.42613-06	.54510
95	1.4700866-04	2.8653929+00	.000000	.000000	.000000	.000000	.000000	.000000	1.44773-06	.54531
96	1.5406846-04	2.9371491+00	.000000	.000000	.000000	.000000	.000000	.000000	1.47000-06	.54565
97	1.6145212-04	3.0119761+00	.000470	.154269	.843932	.000005	.001322	.000002	1.49293-06	.54610
98	1.6917600-04	3.0900964+00	.000000	.000000	.000000	.000000	.000000	.000000	1.51646-06	.54663
99	1.7725750-04	3.1717540+00	.000000	.000000	.000000	.000000	.000000	.000000	1.54054-06	.54717
100	1.8571509-04	3.2572182+00	.000000	.000000	.000000	.000000	.000000	.000000	1.56516-06	.54772
101	1.9456841-04	3.3467853+00	.000000	.000000	.000000	.000000	.000000	.000000	1.59040-06	.54834
102	2.0383830-04	3.4407038+00	.000000	.000000	.000000	.000000	.000000	.000000	1.61621-06	.54911
103	2.1354699-04	3.5395781+00	.000000	.000000	.000000	.000000	.000000	.000000	1.64263-06	.55013
104	2.2371811-04	3.6435724+00	.000000	.000000	.000000	.000000	.000000	.000000	1.66969-06	.55146
105	2.3437681-04	3.7532192+00	.001032	.110203	.883096	.000060	.005566	.000043	1.69737-06	.55309
106	2.4554995-04	3.8690231+00	.000000	.000000	.000000	.000000	.000000	.000000	1.72592-06	.55496
107	2.5726611-04	3.9915526+00	.000000	.000000	.000000	.000000	.000000	.000000	1.75613-06	.55703
108	2.6955584-04	4.1214456+00	.000000	.000000	.000000	.000000	.000000	.000000	1.78803-06	.55932
109	2.8245172-04	4.2594248+00	.000000	.000000	.000000	.000000	.000000	.000000	1.82085-06	.56182
110	2.9598857-04	4.4063094+00	.000000	.000000	.000000	.000000	.000000	.000000	1.85345-06	.56455
111	3.1020360-04	4.5630339+00	.000000	.000000	.000000	.000000	.000000	.000000	1.88469-06	.56754
112	3.2513665-04	4.7306672+00	.000000	.000000	.000000	.000000	.000000	.000000	1.91381-06	.57078

NO.	YRAR	O/F	C(H)	C(H2)	C(H2O)	C(O)	C(OH)	C(O2)	MI	PR
113	3.4083034-04	4.9104379+00	.001871	.064200	.909476	.000736	.022789	.000929	1.94082-06	.57428
114	3.5733326-04	5.1037661+00	.000000	.000000	.000000	.000000	.000000	.000000	1.95654-06	.57804
115	3.7468539-04	5.3123029+00	.000000	.000000	.000000	.000000	.000000	.000000	1.97120-06	.58203
116	3.9294817-04	5.5379768+00	.000000	.000000	.000000	.000000	.000000	.000000	1.98482-06	.58628
117	4.1217484-04	5.7830561+00	.000000	.000000	.000000	.000000	.000000	.000000	2.03739-06	.59077
118	4.3242593-04	6.0502291+00	.000000	.000000	.000000	.000000	.000000	.000000	2.05891-06	.59550
119	4.5376637-04	6.2902237+00	.000000	.000000	.000000	.000000	.000000	.000000	2.07939-06	.60048
120	4.7626594-04	6.2902237+00	.000000	.000000	.000000	.000000	.000000	.000000	2.09881-06	.60570
121	4.9999990-04	6.2902237+00	.002069	.031614	.894261	.004104	.057689	.010264	2.11719-06	.61117

NO. ITERATIONS = 0

POINT WAS ADDED TO BOUNDARY LAYER IN SUBROUTINE ENERGY AT STATION 3 AND ITERATION 0

POINT WAS ADDED TO BOUNDARY LAYER IN SUBROUTINE ENERGY AT STATION 13 AND ITERATION 0

EQUILIBRIUM TEST CASE

STATION	X	S	DS	RW	THETAW	ZETA	ZETAP
20	-3.5448903+00	6.7099997-03	9.3212724-04	1.7227900+00	0.0000000	1.4345054-03	1.2240833-02

EDGE AND WALL CONDITIONS

UE	=	.3776677+03	ME	=	.7271023-01	DELTA*	=	.1378412-03	CF = .3002602-02
TE	=	.6647882+04	RHOE	=	.1884861-01	THETA	=	.3696071-04	ST = .6721354-02
HE	=	-.7968893+07	MUE	=	.2117190-05	TAUW	=	.4036141+01	
PE	=	.4446425+06	TW	=	.1400000+04	QW	=	.1177993+07	
			MDOTW	=	.7385518-02				

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
1	0.0000000	-0.0000000	0.0000000	3.8786747+00	1.2403462+00	1.7230113+00	0.0000000	1400.6
2	4.7049335-09	9.2455547-03	1.1802491-04	3.8778224+00	1.2404249+00	1.7230113+00	3.6421070-15	1400.5
3	1.0919864-08	1.8491109-02	2.7404296-04	3.8766941+00	1.2403618+00	1.7230113+00	1.2692661-12	1400.6
4	1.8934139-08	2.7736664-02	4.7537205-04	3.8752352+00	1.2401571+00	1.7230114+00	5.7190688-12	1400.9
5	2.9065613-08	3.6982219-02	7.3000894-04	3.8733879+00	1.2398106+00	1.7230115+00	2.1364553-11	1401.4
6	4.1658073-08	4.6227773-02	1.0465925-03	3.8710883+00	1.2393224+00	1.7230118+00	6.9670508-11	1402.1
7	5.7081264-08	5.5473328-02	1.4344006-03	3.8682686+00	1.2386925+00	1.7230125+00	2.0467653-10	1403.0
8	7.5730930-08	6.4718882-02	1.9033487-03	3.8648560+00	1.2379209+00	1.7230137+00	5.5309415-10	1404.1
9	9.8028854-08	7.3964437-02	2.4639865-03	3.8607732+00	1.2370076+00	1.7230159+00	1.3951556-09	1405.5
10	1.2442292-07	8.3209991-02	3.1275006-03	3.8559378+00	1.2359726+00	1.7230193+00	3.3203191-09	1407.0
11	1.5538718-07	9.2455546-02	3.9057297-03	3.8502622+00	1.2348898+00	1.7230248+00	7.5150187-09	1408.6
12	1.9142192-07	1.0170110-01	4.8111705-03	3.8436542+00	1.2337338+00	1.7230330+00	1.6275006-08	1410.2
13	2.3305377-07	1.1094666-01	5.8569539-03	3.8360161+00	1.2324787+00	1.7230451+00	3.3886588-08	1412.0
14	2.8083581-07	1.2019221-01	7.0568054-03	3.8272458+00	1.2309991+00	1.7230626+00	6.8099587-08	1414.2
15	3.3534765-07	1.2943777-01	8.4250071-03	3.8172363+00	1.2292268+00	1.7230873+00	1.3252745-07	1416.8
16	3.9719565-07	1.3868332-01	9.9763764-03	3.8058762+00	1.2270929+00	1.7231214+00	2.5049607-07	1420.0
17	4.6701304-07	1.4792888-01	1.1726275-02	3.7930495+00	1.2245949+00	1.7231677+00	4.6108216-07	1423.7
18	5.4546006-07	1.5717443-01	1.3690675-02	3.7786353+00	1.2218283+00	1.7232295+00	8.2832107-07	1427.9
19	6.3322426-07	1.6641998-01	1.5886240-02	3.7625051+00	1.2188611+00	1.7233135+00	1.4548928-06	1432.4
20	7.3102067-07	1.7566554-01	1.8330316-02	3.7445246+00	1.2156986+00	1.7234154+00	2.5020044-06	1437.0
21	8.3959206-07	1.8491109-01	2.1040820-02	3.7245537+00	1.2122847+00	1.7235496+00	4.2176227-06	1442.1
22	9.5970928-07	1.9415665-01	2.4036126-02	3.7024497+00	1.2085339+00	1.7237195+00	6.9759472-06	1447.7
23	1.0921716-06	2.0340221-01	2.7334949-02	3.6780681+00	1.2043611+00	1.7239325+00	1.1332439-05	1454.1
24	1.2378069-06	2.1264776-01	3.0956320-02	3.6512645+00	1.1997099+00	1.7241970+00	1.8100821-05	1461.5
25	1.3974723-06	2.2189331-01	3.4919616-02	3.6218952+00	1.1945818+00	1.7245217+00	2.8457943-05	1469.8
26	1.5720544-06	2.3113887-01	3.9244746-02	3.5898157+00	1.1890372+00	1.7249157+00	4.4081087-05	1478.9
27	1.7624699-06	2.4038442-01	4.3952326-02	3.5548780+00	1.1830962+00	1.7253885+00	6.7323246-05	1488.4
28	1.9696863-06	2.4962997-01	4.9063550-02	3.5169329+00	1.1767589+00	1.7259508+00	1.0143186-04	1498.5
29	2.1946219-06	2.5887553-01	5.4599838-02	3.4758412+00	1.1700238+00	1.7266140+00	1.5081477-04	1509.3
30	2.4383467-06	2.6812109-01	6.0582451-02	3.4314829+00	1.1628886+00	1.7273886+00	2.2136313-04	1520.9
31	2.7018838-06	2.7736664-01	6.7032114-02	3.3837652+00	1.1553510+00	1.7282824+00	3.2085266-04	1533.8
32	2.9863089-06	2.8661220-01	7.3968757-02	3.3326244+00	1.1474095+00	1.7292973+00	4.5945219-04	1547.9
33	3.2927319-06	2.9585775-01	8.1411353-02	3.2780211+00	1.1390643+00	1.7304281+00	6.5030593-04	1563.4
34	3.6222974-06	3.0510330-01	8.9377986-02	3.2199239+00	1.1302926+00	1.7316616+00	9.1016658-04	1580.0
35	3.9761864-06	3.1434886-01	9.7885720-02	3.1582914+00	1.1210168+00	1.7329770+00	1.2600585-03	1597.5
36	4.3556163-06	3.2359441-01	1.0694989-01	3.0930678+00	1.1112349+00	1.7343477+00	1.7259223-03	1615.9
37	4.7618423-06	3.3283997-01	1.1658317-01	3.0241971+00	1.1010206+00	1.7357440+00	2.3391845-03	1635.4
38	5.1961591-06	3.4208553-01	1.2679454-01	2.9516286+00	1.0904849+00	1.7371339+00	3.1372798-03	1656.1
39	5.6599016-06	3.5133108-01	1.3758830-01	2.8753177+00	1.0797391+00	1.7384828+00	4.1641787-03	1678.2
40	6.1544442-06	3.6057663-01	1.4896341-01	2.7952202+00	1.0688566+00	1.7397520+00	5.4708190-03	1702.0
41	6.6812134-06	3.6982219-01	1.6091334-01	2.7112851+00	1.0578354+00	1.7408946+00	7.1150722-03	1727.3
42	7.2416676-06	3.7906774-01	1.7342634-01	2.6234469+00	1.0465521+00	1.7418474+00	9.1617189-03	1754.0
43	7.8373197-06	3.8831329-01	1.8648513-01	2.5316387+00	1.0348355+00	1.7425278+00	1.1682339-02	1782.1
44	8.4697294-06	3.9755885-01	2.0006683-01	2.4358319+00	1.0226820+00	1.7428483+00	1.4754886-02	1811.6
45	9.1405065-06	4.0680441-01	2.1414316-01	2.3360773+00	1.0102297+00	1.7427248+00	1.8462940-02	1842.4

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	PCV	EPS	T
46	9.8513126-06	4.1604996-01	2.2868036-01	2.2325237+00	9.9768748-01	1.7420815+00	2.2895133-02	1874,7
47	1.0603864-05	4.2529552-01	2.4363898-01	2.1254160+00	9.8526430-01	1.7408532+00	2.8144147-02	1908,4
48	1.1399935-05	4.3454107-01	2.5897437-01	2.0150769+00	9.7309821-01	1.7389836+00	3.4304593-02	1943,6
49	1.2241357-05	4.4378663-01	2.7463853-01	1.9018790+00	9.6118568-01	1.7364112+00	4.1471216-02	1980,2
50	1.3130024-05	4.5303218-01	2.9058218-01	1.7862093+00	9.4934109-01	1.7330396+00	4.9739140-02	2018,4
51	1.4067897-05	4.6227773-01	3.0675592-01	1.6684372+00	9.3739390-01	1.7287559+00	5.9204575-02	2058,1
52	1.5057002-05	4.7152329-01	3.2311158-01	1.5489189+00	9.2534112-01	1.7234711+00	6.9965334-02	2099,3
53	1.6099437-05	4.8076884-01	3.3960320-01	1.4280212+00	9.1330028-01	1.7171285+00	8.2121998-02	2142,0
54	1.7197376-05	4.9001440-01	3.5618665-01	1.3061310+00	9.0144923-01	1.7097010+00	9.5779091-02	2186,1
55	1.8353070-05	4.9925996-01	3.7281896-01	1.1836607+00	8.8996577-01	1.7011841+00	1.1104406-01	2231,4
56	1.9568852-05	5.0850550-01	3.8945835-01	1.0610488+00	8.7896746-01	1.6915953+00	1.2802313-01	2277,8
57	2.0847142-05	5.1775106-01	4.0606579-01	9.3876727-01	8.6845128-01	1.6809240+00	1.4682122-01	2325,5
58	2.2190449-05	5.2699661-01	4.2260641-01	8.1731294-01	8.5827500-01	1.6691234+00	1.6754366-01	2374,4
59	2.3601381-05	5.3624216-01	4.3904895-01	6.9717290-01	8.4834432-01	1.6561377+00	1.9029557-01	2424,8
60	2.5082645-05	5.4543772-01	4.5536577-01	5.7882588-01	8.3865793-01	1.6419623+00	2.1517926-01	2476,5
61	2.6637051-05	5.5473328-01	4.7153265-01	4.6275734-01	8.2926805-01	1.6266354+00	2.4229620-01	2529,5
62	2.8267524-05	5.6397883-01	4.8752730-01	3.4944451-01	8.2025367-01	1.6102391+00	2.7174992-01	2583,8
63	2.9977106-05	5.7322439-01	5.0332816-01	2.3935197-01	8.1169380-01	1.5929021+00	3.0363951-01	2639,0
64	3.1768961-05	5.8246994-01	5.1891527-01	1.3294292-01	8.0364061-01	1.5747903+00	3.3805372-01	2695,3
65	3.3646388-05	5.9171550-01	5.3427164-01	3.0674889-02	7.9609281-01	1.5560651+00	3.7509523-01	2752,4
66	3.5612819-05	6.0096105-01	5.4938032-01	-6.7035187-02	7.8899257-01	1.5368701+00	4.1487887-01	2810,7
67	3.7671836-05	6.1020660-01	5.6422614-01	-1.5978400-01	7.8231535-01	1.5174401+00	4.5744594-01	2870,1
68	3.9827178-05	6.1945216-01	5.7880089-01	-2.4717134-01	7.7606100-01	1.4980623+00	5.0286727-01	2930,8
69	4.2082738-05	6.2869772-01	5.9309557-01	-3.2487003-01	7.7023640-01	1.4790103+00	5.5142475-01	2992,5
70	4.4442589-05	6.3794327-01	6.0708608-01	-4.0466870-01	7.6485195-01	1.4607042+00	6.0271052-01	3055,3
71	4.6910989-05	6.4718883-01	6.2077820-01	-4.7409882-01	7.5991805-01	1.4435743+00	6.5723792-01	3118,9
72	4.9492378-05	6.5643436-01	6.3419490-01	-5.3665640-01	7.5544158-01	1.4275449+00	7.1489517-01	3183,3
73	5.2191412-05	6.6567993-01	6.4720737-01	-5.9383404-01	7.5142238-01	1.4135981+00	7.7543113-01	3248,5
74	5.5012962-05	6.7492549-01	6.6002532-01	-6.4200722-01	7.4786101-01	1.4017204+00	8.3921394-01	3314,7
75	5.7962124-05	6.8417104-01	6.7239302-01	-6.8549397-01	7.4478074-01	1.3925034+00	9.0612027-01	3382,0
76	6.1044243-05	6.9341660-01	6.8451998-01	-7.2036240-01	7.4218221-01	1.3871343+00	9.7604152-01	3450,6
77	6.4264923-05	7.0266216-01	6.9626652-01	-7.4903986-01	7.4004138-01	1.3857392+00	1.0490093+00	3520,1
78	6.7630034-05	7.1190771-01	7.0769463-01	-7.7053071-01	7.3832199-01	1.3893057+00	1.1253615+00	3590,3
79	7.1145748-05	7.2115326-01	7.1878181-01	-7.8521458-01	7.3698768-01	1.3980523+00	1.2045479+00	3660,9
80	7.4818547-05	7.3039882-01	7.2953063-01	-7.9324060-01	7.3601449-01	1.4123253+00	1.2871111+00	3731,7
81	7.8655230-05	7.3964437-01	7.3994223-01	-7.9479699-01	7.3540300-01	1.4324110+00	1.3725587+00	3802,6
82	8.2662956-05	7.4888992-01	7.5001698-01	-7.9014765-01	7.3519564-01	1.4588517+00	1.4608958+00	3874,0
83	8.6849257-05	7.5813548-01	7.5975607-01	-7.7959773-01	7.3545493-01	1.4925910+00	1.5519187+00	3946,4
84	9.1222051-05	7.6738103-01	7.6916087-01	-7.6349515-01	7.3618215-01	1.5346244+00	1.6454977+00	4019,7
85	9.5789686-05	7.7662659-01	7.7823345-01	-7.4222882-01	7.3732598-01	1.5857258+00	1.7415890+00	4093,7
86	1.0056096-04	7.8587215-01	7.8697667-01	-7.1622166-01	7.3880887-01	1.6462744+00	1.8402351+00	4167,7
87	1.0554513-04	7.9511770-01	7.9539427-01	-6.8592425-01	7.4055316-01	1.7161993+00	1.9414613+00	4241,2
88	1.1075198-04	8.0436325-01	8.0349074-01	-6.5180848-01	7.4250757-01	1.7950850+00	2.0450400+00	4314,0
89	1.1619185-04	8.1360881-01	8.1127152-01	-6.1436075-01	7.4467341-01	1.8824898+00	2.1507283+00	4386,1
90	1.2187562-04	8.2285436-01	8.1874134-01	-5.7408150-01	7.4710644-01	1.9783373+00	2.2595195+00	4457,6
91	1.2781481-04	8.3209991-01	8.2590084-01	-5.3149536-01	7.4982747-01	2.0826083+00	2.3742845+00	4528,4
92	1.3402161-04	8.4134547-01	8.3275800-01	-4.8708757-01	7.5283659-01	2.1951558+00	2.4941564+00	4598,4
93	1.4050890-04	8.5059103-01	8.3935088-01	-4.4115798-01	7.5613011-01	2.3154423+00	2.5914577+00	4668,0
94	1.4729030-04	8.5983658-01	8.4572928-01	-3.9387989-01	7.5970256-01	2.4425260+00	2.6655997+00	4737,7
95	1.5438026-04	8.6908214-01	8.5193752-01	-3.4539931-01	7.6354838-01	2.5754735+00	2.7146278+00	4807,9
96	1.6179407-04	8.7832769-01	8.5802422-01	-2.9577225-01	7.6766394-01	2.7134515+00	2.7345622+00	4879,0
97	1.6954798-04	8.8757325-01	8.6403536-01	-2.4501944-01	7.7204937-01	2.8556096+00	2.7250537+00	4951,0
98	1.7765917-04	8.9681880-01	8.6999469-01	-1.9327247-01	7.7666628-01	3.0008995+00	2.7126023+00	5023,3
99	1.8614590-04	9.0606435-01	8.7591393-01	-1.4071698-01	7.8137945-01	3.1473441+00	2.6963460+00	5095,5
100	1.9502760-04	9.1530991-01	8.8180743-01	-8.7492462-02	7.8618561-01	3.2934590+00	2.6752021+00	5167,5
101	2.0432485-04	9.2455547-01	8.8768864-01	-3.3715957-02	7.9121298-01	3.4389669+00	2.6478326+00	5239,8
102	2.1405958-04	9.3380102-01	8.9357140-01	2.0932455-02	7.9665555-01	3.5851406+00	2.6126199+00	5312,9

NO.	YBAR	Y	U/UE	H/HE	RO/ROE	ROV	EPS	T
103	2.2425510-04	9.4304658-01	8.9947027-01	7.5212088-02	8.0270734-01	3.7346479+00	2.5676657+00	5387,6
104	2.3493623-04	9.5229213-01	9.0540025-01	1.3031860-01	8.0949657-01	3.8908662+00	2.5108322+00	5464,2
105	2.4612941-04	9.6153768-01	9.1137710-01	1.8588514-01	8.1701998-01	4.0365731+00	2.4398495+00	5542,7
106	2.5786281-04	9.7078324-01	9.1741793-01	2.4198118-01	8.2517773-01	4.2331183+00	2.3525132+00	5623,5
107	2.7016647-04	9.8002879-01	9.2354020-01	2.9869869-01	8.3404619-01	4.4229729+00	2.2469857+00	5709,1
108	2.8307245-04	9.8927435-01	9.2976067-01	3.5613858-01	8.4362824-01	4.6275327+00	2.1221875+00	5799,4
109	2.9661499-04	9.9851990-01	9.3609538-01	4.1440456-01	8.5381245-01	4.8467562+00	1.9782270+00	5892,1
110	3.1083062-04	1.0077655+00	9.4255835-01	4.7358663-01	8.6443029-01	5.0798126+00	1.8167640+00	5983,5
111	3.2575845-04	1.0170110+00	9.4915829-01	5.3372607-01	8.7531318-01	5.3258314+00	1.6411839+00	6069,9
112	3.4144031-04	1.0262566+00	9.5589253-01	5.9475549-01	8.8634977-01	5.5847 [illegible]5+00	1.4564718+00	6148,8
113	3.5792094-04	1.0355021+00	9.6273693-01	6.5640400-01	8.9754291-01	5.8582152+00	1.2687504+00	6220,4
114	3.7524824-04	1.0447477+00	9.6962906-01	7.1805550-01	9.0940591-01	6.1568616+00	1.0845525+00	6288,1
115	3.9347363-04	1.0539932+00	9.7644334-01	7.7857286-01	9.2325225-01	6.5088732+00	9.0999068-01	6355,7
116	4.1265217-04	1.0632388+00	9.8296540-01	8.3615263-01	9.3911271-01	6.9246454+00	7.5002475-01	6423,3
117	4.3284295-04	1.0724843+00	9.8887143-01	8.8827468-01	9.5578737-01	7.3888564+00	6.0799435-01	6488,1
118	4.5410950-04	1.0817299+00	9.9373836-01	9.3191971-01	9.7146113-01	7.8618436+00	4.8549069-01	6545,8
119	4.7652004-04	1.0909754+00	9.9716400-01	9.6438735-01	9.8431882-01	8.2853001+00	3.8252952-01	6592,3
120	5.0014783-04	1.1002210+00	9.9904405-01	9.8474374-01	9.9316058-01	8.6014114+00	2.9793011-01	6624,7
121	5.2507190-04	1.1094666+00	9.9977495-01	9.9489826-01	9.9801718-01	8.7882631+00	2.2974926-01	6643,1
122	5.5137720-04	1.1187121+00	9.9996568-01	9.9878411-01	1.0001654+00	8.8711301+00	1.6409747-01	6650,5
123	5.7915526-04	1.1279577+00	1.0000000+00	1.0000000+00	1.0000000+00	8.8567821+00	1.2406790-01	6647,9

EQUILIBRIUM TEST CASE

NO.	YBAR	O/F	C(H)	C(H2)	C(H2O)	C(O)	C(OH)	C(O2)	MU	PR
1	0.0000000	8.1699194-01	.000000	.493706	.506294	.000000	.000000	.000000	4.36348-07	.55793
2	4.7049335-09	8.1705880-01	.000000	.000000	.000000	.000000	.000000	.000000	4.36314-07	.55793
3	1.0919464-08	8.1714701-01	.000000	.000000	.000000	.000000	.000000	.000000	4.36335-07	.55793
4	1.8934139-08	8.1726059-01	.000000	.000000	.000000	.000000	.000000	.000000	4.36411-07	.55793
5	2.9065613-08	8.1740384-01	.000000	.000000	.000000	.000000	.000000	.000000	4.36540-07	.55793
6	4.1658073-08	8.1758154-01	.000000	.000000	.000000	.000000	.000000	.000000	4.36725-07	.55793
7	5.7081264-08	8.1779895-01	.000000	.000000	.000000	.000000	.000000	.000000	4.36963-07	.55794
8	7.5730930-08	8.1806159-01	.000000	.000000	.000000	.000000	.000000	.000000	4.37256-07	.55794
9	9.8028854-08	8.1837557-01	.000000	.493234	.506746	.000000	.000000	.000000	4.37603-07	.55794
10	1.2442292-07	8.1874690-01	.000000	.000000	.000000	.000000	.000000	.000000	4.37996-07	.55795
11	1.5538718-07	8.1918235-01	.000000	.000000	.000000	.000000	.000000	.000000	4.38408-07	.55796
12	1.9142192-07	8.1968854-01	.000000	.000000	.000000	.000000	.000000	.000000	4.38837-07	.55796
13	2.3305377-07	8.2027300-01	.000000	.000000	.000000	.000000	.000000	.000000	4.39310-07	.55797
14	2.8083581-07	8.2094304-01	.000000	.000000	.000000	.000000	.000000	.000000	4.39866-07	.55798
15	3.3534765-07	8.2170659-01	.000000	.000000	.000000	.000000	.000000	.000000	4.40543-07	.55799
16	3.9719565-07	8.2257186-01	.000000	.000000	.000000	.000000	.000000	.000000	4.41368-07	.55800
17	4.6701304-07	8.2354739-01	.000000	.491478	.508522	.000000	.000000	.000000	4.42339-07	.55801
18	5.4546006-07	8.2464195-01	.000000	.000000	.000000	.000000	.000000	.000000	4.43417-07	.55803
19	6.3322426-07	8.2586487-01	.000000	.000000	.000000	.000000	.000000	.000000	4.44555-07	.55804
20	7.3102067-07	8.2722520-01	.000000	.000000	.000000	.000000	.000000	.000000	4.45752-07	.55806
21	8.3959206-07	8.2873248-01	.000000	.000000	.000000	.000000	.000000	.000000	4.47044-07	.55808
22	9.5970928-07	8.3039691-01	.000000	.000000	.000000	.000000	.000000	.000000	4.48488-07	.55810
23	1.0921716-06	8.3222906-01	.000000	.000000	.000000	.000000	.000000	.000000	4.50137-07	.55812
24	1.2378069-06	8.3424014-01	.000000	.000000	.000000	.000000	.000000	.000000	4.52029-07	.55815
25	1.3974723-06	8.3644161-01	.000000	.487142	.512858	.000000	.000000	.000000	4.54163-07	.55817
26	1.5720544-06	8.3884616-01	.000000	.000000	.000000	.000000	.000000	.000000	4.56485-07	.55820
27	1.7624699-06	8.4146630-01	.000000	.000000	.000000	.000000	.000000	.000000	4.58937-07	.55823
28	1.9696663-06	8.4431547-01	.000000	.000000	.000000	.000000	.000000	.000000	4.61516-07	.55827
29	2.1946219-06	8.4740845-01	.000000	.000000	.000000	.000000	.000000	.000000	4.64268-07	.55831
30	2.4383467-06	8.5076175-01	.000000	.000000	.000000	.000000	.000000	.000000	4.67259-07	.55835
31	2.7018838-06	8.5439490-01	.000000	.000000	.000000	.000000	.000000	.000000	4.70557-07	.55839
32	2.9863089-06	8.5833005-01	.000000	.000000	.000000	.000000	.000000	.000000	4.74205-07	.55842
33	3.2927319-06	8.6259162-01	.000000	.478534	.521466	.000000	.000000	.000000	4.78202-07	.55846
34	3.6222974-06	8.6720436-01	.000000	.000000	.000000	.000000	.000000	.000000	4.82491-07	.55850
35	3.9761864-06	8.7219134-01	.000000	.000000	.000000	.000000	.000000	.000000	4.87017-07	.55853
36	4.3556163-06	8.7757332-01	.000000	.000000	.000000	.000000	.000000	.000000	4.91781-07	.55857
37	4.7618423-06	8.8336986-01	.000000	.000000	.000000	.000000	.000000	.000000	4.96817-07	.55860
38	5.1961591-06	8.8960014-01	.000000	.000000	.000000	.000000	.000000	.000000	5.02180-07	.55864
39	5.6599016-06	8.9628214-01	.000000	.000000	.000000	.000000	.000000	.000000	5.07924-07	.55867
40	6.1544462-06	9.0343230-01	.000000	.000000	.000000	.000000	.000000	.000000	5.14085-07	.55871
41	6.6812134-06	9.1106378-01	.000000	.463201	.536799	.000000	.000000	.000000	5.20660-07	.55874
42	7.2416676-06	9.1918606-01	.000000	.000000	.000000	.000000	.000000	.000000	5.27610-07	.55878
43	7.8373197-06	9.2780466-01	.000000	.000000	.000000	.000000	.000000	.000000	5.34914-07	.55882
44	8.4697294-06	9.3692575-01	.000000	.000000	.000000	.000000	.000000	.000000	5.42571-07	.55887
45	9.1405065-06	9.4656171-01	.000000	.000000	.000000	.000000	.000000	.000000	5.50590-07	.55892
46	9.8513126-06	9.5673332-01	.000000	.000000	.000000	.000000	.000000	.000000	5.58984-07	.55896
47	1.0603864-05	9.6746805-01	.000000	.000000	.000000	.000000	.000000	.000000	5.67767-07	.55899
48	1.1399935-05	9.7879741-01	.000000	.000000	.000000	.000000	.000000	.000000	5.76946-07	.55900
49	1.2241357-05	9.9075472-01	.000000	.439615	.560386	.000000	.000000	.000000	5.86523-07	.55898
50	1.3130024-05	1.0033718+00	.000000	.000000	.000000	.000000	.000000	.000000	5.96486-07	.55895
51	1.4067897-05	1.0166743+00	.000000	.000000	.000000	.000000	.000000	.000000	6.06833-07	.55891
52	1.5057002-05	1.0306842+00	.000000	.000000	.000000	.000000	.000000	.000000	6.17563-07	.55887
53	1.6099437-05	1.0454265+00	.000000	.000000	.000000	.000000	.000000	.000000	6.28677-07	.55882
54	1.7197376-05	1.0609290+00	.000000	.000000	.000000	.000000	.000000	.000000	6.40177-07	.55874
55	1.8353070-05	1.0772204+00	.000000	.000000	.000000	.000000	.000000	.000000	6.52064-07	.55864

NO.	YBAR	O/F	C(H)	C(H2)	C(H2O)	C(O)	C(OH)	C(O2)	[illegible]	PR
56	1.9568852-05	1.0943297+00	.000000	.000000	.000000	.000000	.000000	.000000	6.64341-07	.55851
57	2.0847142-05	1.1122906+00	.000000	.407071	.592929	.000000	.000000	.000000	6.77096-07	.55834
58	2.2190449-05	1.1311438+00	.000000	.000000	.000000	.000000	.000000	.000000	6.90065-07	.55815
59	2.3601381-05	1.1509294+00	.000000	.000000	.000000	.000000	.000000	.000000	7.03476-07	.55793
60	2.5082645-05	1.1716852+00	.000000	.000000	.000000	.000000	.000000	.000000	7.17249-07	.55769
61	2.6637051-05	1.1934688+00	.000000	.000000	.000000	.000000	.000000	.000000	7.31444-07	.55742
62	2.8267524-05	1.2163203+00	.000000	.000000	.000000	.000000	.000000	.000000	7.46018-07	.55713
63	2.9977186-05	1.2402894+00	.000000	.000000	.000000	.000000	.000000	.000000	7.61009-07	.55682
64	3.1768961-05	1.2654265+00	.000000	.000000	.000000	.000000	.000000	.000000	7.76427-07	.55647
65	3.3646388-05	1.2917882+00	.000000	.365319	.634681	.000000	.000000	.000000	7.92272-07	.55610
66	3.5612819-05	1.3194233+00	.000000	.000000	.000000	.000000	.000000	.000000	8.08527-07	.55571
67	3.7671836-05	1.3483868+00	.000000	.000000	.000000	.000000	.000000	.000000	8.25174-07	.55527
68	3.9827178-05	1.3787501+00	.000000	.000000	.000000	.000000	.000000	.000000	8.42212-07	.55480
69	4.2082738-05	1.4105657+00	.000000	.000000	.000000	.000000	.000000	.000000	8.59654-07	.55430
70	4.4442589-05	1.4438366+00	.000000	.000000	.000000	.000000	.000000	.000000	8.77525-07	.55379
71	4.6910989-05	1.4787249+00	.000000	.000000	.000000	.000000	.000000	.000000	8.95846-07	.55327
72	4.9492378-05	1.5154485+00	.000000	.000000	.000000	.000000	.000000	.000000	9.14631-07	.55275
73	5.2191412-05	1.5531010+00	.000004	.315028	.684966	.000000	.000001	.000000	9.33880-07	.55223
74	5.5012962-05	1.5937514+00	.000000	.000000	.000000	.000000	.000000	.000000	9.53595-07	.55170
75	5.7962124-05	1.6348415+00	.000300	.000000	.000000	.000000	.000000	.000000	9.73821-07	.55113
76	6.1044243-05	1.6787608+00	.000000	.000000	.000000	.000000	.000000	.000000	9.94559-07	.55054
77	6.4264923-05	1.7240479+00	.000000	.000000	.000000	.000000	.000000	.000000	1.01576-06	.54993
78	6.7630034-05	1.7714039+00	.000000	.000000	.000000	.000000	.000000	.000000	1.03736-06	.54932
79	7.1145748-05	1.8206819+00	.000000	.000000	.000000	.000000	.000000	.000000	1.05927-06	.54875
80	7.4818547-05	1.8719090+00	.000000	.000000	.000000	.000000	.000000	.000000	1.08144-06	.54823
81	7.8655230-05	1.9251126+00	.000000	.258909	.741034	.000000	.000023	.000000	1.10389-06	.54776
82	8.2662956-05	1.9802881+00	.000000	.000000	.000000	.000000	.000000	.000000	1.12670-06	.54732
83	8.6849257-05	2.0374165+00	.000000	.000000	.000000	.000000	.000000	.000000	1.15003-06	.54688
84	9.1222051-05	2.0964625+00	.000000	.000000	.000000	.000000	.000000	.000000	1.17389-06	.54644
85	9.5789686-05	2.1573742+00	.000000	.000000	.000000	.000000	.000000	.000000	1.19813-06	.54603
86	1.0056096-04	2.2200855+00	.000000	.000000	.000000	.000000	.000000	.000000	1.22257-06	.54566
87	1.0554513-04	2.2845157+00	.000000	.000000	.000000	.000000	.000000	.000000	1.24700-06	.54535
88	1.1075198-04	2.3505691+00	.000000	.000000	.000000	.000000	.000000	.000000	1.27131-06	.54513
89	1.1619185-04	2.4181341+00	.000158	.203275	.796341	.000000	.000226	.000000	1.29549-06	.54499
90	1.2187562-04	2.4870732+00	.000000	.000000	.000000	.000000	.000000	.000000	1.31964-06	.54491
91	1.2781481-04	2.5571936+00	.000000	.000000	.000000	.000000	.000000	.000000	1.34373-06	.54486
92	1.3402161-04	2.6283353+00	.000000	.000000	.000000	.000000	.000000	.000000	1.36775-06	.54485
93	1.4050890-04	2.7005905+00	.000000	.000000	.000000	.000000	.000000	.000000	1.39179-06	.54490
94	1.4729030-04	2.7742088+00	.000000	.000000	.000000	.000000	.000000	.000000	1.41597-06	.54502
95	1.5438026-04	2.8494642+00	.000000	.000000	.000000	.000000	.000000	.000000	1.44043-06	.54525
96	1.6179407-04	2.9267468+00	.000000	.000000	.000000	.000000	.000000	.000000	1.46526-06	.54559
97	1.6954798-04	3.0065025+00	.000463	.154658	.843580	.000005	.001292	.000002	1.49045-06	.54606
98	1.7765917-04	3.0890143+00	.000000	.000000	.000000	.000000	.000000	.000000	1.51587-06	.54660
99	1.8614590-04	3.1744789+00	.000000	.000000	.000000	.000000	.000000	.000000	1.54130-06	.54716
100	1.9502760-04	3.2631621+00	.000000	.000000	.000000	.000000	.000000	.000000	1.56676-06	.54772
101	2.0432485-04	3.3553657+00	.000000	.000000	.000000	.000000	.000000	.000000	1.59239-06	.54835
102	2.1405958-04	3.4514540+00	.000000	.000000	.000000	.000000	.000000	.000000	1.61843-06	.54915
103	2.2425510-04	3.5518639+00	.000000	.000000	.000000	.000000	.000000	.000000	1.64514-06	.55020
104	2.3493623-04	3.6571126+00	.000000	.000000	.000000	.000000	.000000	.000000	1.67266-06	.55158
105	2.4612941-04	3.7678155+00	.001044	.109474	.883680	.000062	.005694	.000045	1.70099-06	.55328
106	2.5786281-04	3.8847057+00	.000000	.000000	.000000	.000000	.000000	.000000	1.73025-06	.55524
107	2.7016647-04	4.0086336+00	.000000	.000000	.000000	.000000	.000000	.000000	1.76129-06	.55745
108	2.8307245-04	4.1405639+00	.000000	.000000	.000000	.000000	.000000	.000000	1.79415-06	.55992
109	2.9661499-04	4.2815901+00	.000000	.000000	.000000	.000000	.000000	.000000	1.82795-06	.56262
110	3.1083062-04	4.4329229+00	.000000	.000000	.000000	.000000	.000000	.000000	1.86140-06	.56554
111	3.2575845-04	4.5958203+00	.000000	.000000	.000000	.000000	.000000	.000000	1.89321-06	.56866
112	3.4144031-04	4.7714093+00	.000000	.000000	.000000	.000000	.000000	.000000	1.92250-06	.57196

NO.	YBAR	O/F	C(H)	C(H2)	C(H20)	C(O)	C(OH)	C(02)	MI	PR
113	3.5792C94-04	4.9603230+00	.001896	.062464	.909764	.000799	.023845	.001132	1.94931-06	.57544
114	3.7524824-04	5.1620266+00	.000000	.000000	.000000	.000000	.000000	.000000	1.97495-06	.57926
115	3.9347363-04	5.3737494+00	.000000	.000000	.000000	.000000	.000000	.000000	2.00097-06	.58393
116	4.1265217-04	5.5891554+00	.000000	.000000	.000000	.000000	.000000	.000000	2.02742-06	.58946
117	4.3284295-04	5.7970928+00	.000000	.000000	.000000	.000000	.000000	.000000	2.05309-06	.59537
118	4.5410950-04	5.9815796+00	.000000	.000000	.000000	.000000	.000000	.000000	2.07614-06	.60099
119	4.7652004-04	6.1254481+00	.000000	.000000	.000000	.000000	.000000	.000000	2.09476-06	.60560
120	5.0014783-04	6.2187131+00	.000000	.000000	.000000	.000000	.000000	.000000	2.10773-06	.60876
121	5.2507190-04	6.2661591+00	.002074	.032028	.894911	.004016	.057047	.009923	2.11508-06	.61047
122	5.5137720-04	6.2844744+00	.002069	.031614	.894261	.004104	.057689	.010264	2.11810-06	.61122
123	5.7915526-04	6.2902240+00	.002069	.031614	.894261	.004103	.057688	.010264	2.11719-06	.61117

NO. ITERATIONS = 1

EQUILIBRIUM TEST CASE

STATION X S	RW THETAW DS	UE TE HE	ME PE RHOE	MUE MDOTW TW	CF TAUW ----	ST QW SUMQW	DELTA* THETA ADIMAS	ZETA ZETAP DNEDS	RWPR XPR
.0	1.7228+00	3.7723+02	7.2626-02	2.1172-06	1.3729-03	1.0112-03	1.3534-04	1.3660-03	5.2536-01
-3.5516+00	0.0000	6.6479+03	4.4463+05	0.0000	1.8412+00	-5.2826+05	3.1896-05	3.6023-02	-1.0833+00
0.0000	6.5500-05	-7.9687+06	1.8848-02	1.4000+03	6.6750+00	0.0000	0.0000	-0.0000	
1.0	1.7228+00	3.7723+02	7.2626-02	2.1172-06	1.2860-03	-1.7543-03	1.3548-04	1.3723-03	5.2536-01
-3.5515+00	0.0000	6.6479+03	4.4463+05	7.3854-03	1.7246+00	7.3415+05	3.2039-05	9.5938-02	-1.0833+00
6.5500-05	6.5500-05	-7.9687+06	1.8848-02	1.4000+03	1.6116+01	6.7912+00	2.7740-07	6.5463-02	
2.0	1.7228+00	3.7724+02	7.2627-02	2.1172-06	1.5716-03	-2.1211-03	1.3517-04	1.3784-03	5.2536-01
-3.5515+00	0.0000	6.6479+03	4.4463+05	7.3854-03	2.0407+00	7.2913+05	3.2140-05	8.0712-02	-1.0833+00
1.4082-04	7.5325-05	-7.9687+06	1.8848-02	1.4000+03	8.3438+00	6.2295+01	5.9726-07	6.5431-02	
3.0	1.7228+00	3.7724+02	7.2629-02	2.1172-06	1.6018-03	-2.7537-03	1.3272-04	1.3786-03	5.2536-01
-3.5514+00	0.0000	6.6479+03	4.4463+05	7.3854-03	2.1483+00	8.5447+05	3.2176-05	3.1187-03	-1.0833+00
2.2745-04	8.6624-05	-7.9687+06	1.8848-02	1.4000+03	-3.8329+00	1.3137+02	9.6465-07	6.5454-02	
4.0	1.7228+00	3.7725+02	7.2630-02	2.1172-06	1.8751-03	-3.5614-03	1.3154-04	1.3718-03	5.2536-01
-3.5513+00	0.0000	6.6479+03	4.4463+05	7.3854-03	2.5149+00	9.3642+05	3.2096-05	-6.8702-02	-1.0832+00
3.2707-04	9.9617-05	-7.9687+06	1.8848-02	1.4000+03	-6.8475+00	2.2121+02	1.3871-06	6.5443-02	
5.0	1.7228+00	3.7726+02	7.2631-02	2.1172-06	2.0285-03	-4.7326-03	1.3048-04	1.3624-03	5.2536-01
-3.5512+00	0.0000	6.6479+03	4.4463+05	7.3855-03	2.7207+00	1.0734+06	3.2095-05	-8.1953-02	-1.0832+00
4.4163-04	1.1456-04	-7.9687+06	1.8848-02	1.4000+03	-3.1961+00	3.3715+02	1.8731-06	6.5459-02	
6.0	1.7228+00	3.7727+02	7.2633-02	2.1172-06	2.3113-03	-6.4794-03	1.2985-04	1.3557-03	5.2536-01
-3.5510+00	0.0000	6.6479+03	4.4463+05	7.3854-03	3.1002+00	1.1756+06	3.2177-05	-5.0943-02	-1.0832+00
5.7337-04	1.3174-04	-7.9687+06	1.8848-02	1.4000+03	2.5542+00	4.8635+02	2.4318-06	6.5461-02	
7.0	1.7228+00	3.7728+02	7.2635-02	2.1172-06	2.4108-03	-8.9632-03	1.2962-04	1.3549-03	5.2536-01
-3.5509+00	0.0000	6.6479+03	4.4463+05	7.3854-03	3.3008+00	1.2929+06	3.2332-05	-5.4184-03	-1.0831+00
7.2488-04	1.5151-04	-7.9687+06	1.8848-02	1.4000+03	6.2525+00	6.7468+02	3.0743-06	6.5455-02	
8.0	1.7228+00	3.7729+02	7.2637-02	2.1172-06	2.6922-03	-1.3258-02	1.2964-04	1.3594-03	5.2536-01
-3.5507+00	0.0000	6.6479+03	4.4463+05	7.3854-03	3.6116+00	1.3590+06	3.2511-05	2.6035-02	-1.0831+00
8.9911-04	1.7423-04	-7.9687+06	1.8848-02	1.4000+03	6.2979+00	9.0735+02	3.8133-06	6.5448-02	
9.0	1.7228+00	3.7730+02	7.2640-02	2.1172-06	2.7992-03	-2.0797-02	1.2967-04	1.3659-03	5.2536-01
-3.5505+00	0.0000	6.6479+03	4.4463+05	7.3854-03	3.7553+00	1.4344+06	3.2674-05	3.2376-02	-1.0830+00
1.0995-03	2.0037-04	-7.9688+06	1.8848-02	1.4000+03	4.5766+00	1.1892+03	4.6630-06	6.5464-02	
10.0	1.7228+00	3.7732+02	7.2642-02	2.1172-06	2.9689-03	-4.4045-02	1.2965-04	1.3705-03	5.2536-01
-3.5503+00	0.0000	6.6479+03	4.4463+05	7.3854-03	3.9833+00	1.4560+06	3.2813-05	2.0178-02	-1.0829+00
1.3299-03	2.3042-04	-7.9688+06	1.8848-02	1.4000+03	2.7471+00	1.5246+03	5.6403-06	6.5462-02	
11.0	1.7228+00	3.7733+02	7.2646-02	2.1172-06	3.0278-03	-3.4442-01	1.2962-04	1.3718-03	5.2536-01
-3.5500+00	0.0000	6.6479+03	4.4463+05	7.3854-03	4.0627+00	1.4953+06	3.2959-05	4.7909-03	-1.0828+00
1.5949-03	2.6498-04	-7.9688+06	1.8848-02	1.4000+03	2.3555+00	1.9184+03	6.7641-06	6.5457-02	
12.0	1.7228+00	3.7735+02	7.2650-02	2.1172-06	3.1283-03	5.7147-02	1.2975-04	1.3711-03	5.2536-01
-3.5497+00	0.0000	6.6479+03	4.4463+05	7.3854-03	4.1980+00	1.4733+06	3.3151-05	-2.1966-03	-1.0827+00
1.8996-03	3.0473-04	-7.9688+06	1.8848-02	1.4000+03	3.0371+00	2.3739+03	8.0566-06	6.5464-02	

EQUILIBRIUM TEST CASE

STATION X S	RW THETAW DS	UE TE HE	ME PE RHOE	MUE MDOTW TW	CF TAUW ----	ST QW SUMQW	DELTA* THETA ADDMAS	ZETA ZETAP DUEDS	RWPR XPR
13.0	1.7228+00	3.7738+02	7.2654-02	2.1172-06	3.1289-03	3.0075-02	1.3022-04	1.3716-03	5.2536-01
-3.5494+00	0.0000	6.6479+03	4.4463+05	7.3854-03	4.1993+00	1.4731+06	3.3424-05	1.3457-03	-1.0826+00
2.2501-03	3.5044-04	-7.9688+06	1.8848-02	1.4000+03	4.3558+00	2.8939+03	9.5428-06	6.5461-02	
14.0	1.7228+00	3.7740+02	7.2659-02	2.1172-06	3.1631-03	1.9299-02	1.3092-04	1.3756-03	5.2536-01
-3.5489+00	0.0000	6.6479+03	4.4464+05	7.3854-03	4.2458+00	1.4146+06	3.3772-05	9.9046-03	-1.0825+00
2.6531-03	4.0301-04	-7.9688+06	1.8848-02	1.4000+03	5.1280+00	3.4799+03	1.1252-05	6.5464- 2	
15.0	1.7228+00	3.7743+02	7.2665-02	2.1172-06	3.1285-03	1.5250-02	1.3181-04	1.3834-03	5.2536-01
-3.5485+00	0.0000	6.6479+03	4.4464+05	7.3855-03	4.2000+00	1.3903+06	3.4183-05	1.6838-02	-1.0824+00
3.1165-03	4.6346-04	-7.9688+06	1.8848-02	1.4000+03	5.3339+00	4.1345+03	1.3218-05	6.5462-02	
16.0	1.7228+00	3.7747+02	7.2672-02	2.1172-06	3.1709-03	1.1917-02	1.3280-04	1.3935-03	5.2536-01
3.5480+00	0.0000	6.6479+03	4.4464+05	7.3855-03	4.2041+00	1.3158+06	3.4627-05	1.8930-02	-1.0822+00
3.6495-03	5.3298-04	-7.9688+06	1.8848-02	1.4000+03	4.8701+00	4.8608+03	1.5478-05	6.5464-02	
17.0	1.7228+00	3.7751+02	7.2679-02	2.1172-06	3.0889-03	1.0363-02	1.3383-04	1.4039-03	5.2536-01
-3.5473+00	0.0000	6.6479+03	4.4464+05	7.3855-03	4.1486+00	1.2881+06	3.5107-05	1.6885-02	-1.0820+00
4.2624-03	6.1292-04	-7.9688+06	1.8848-02	1.4000+03	4.4332+00	5.6645+03	1.8078-05	6.5465-02	
18.0	1.7228+00	3.7755+02	7.2688-02	2.1172-06	3.0755-03	8.6451-03	1.3495-04	1.4135-03	5.2536-01
-3.5466+00	0.0000	6.6479+03	4.4464+05	7.3855-03	4.1316+00	1.2112+06	3.5634-05	1.3640-02	-1.0818+00
4.9673-03	7.0486-04	-7.9689+06	1.8848-02	1.4000+03	4.1262+00	6.5516+03	2.1067-05	6.5462-02	
19.0	1.7228+00	3.7761+02	7.2698-02	2.1172-06	3.0310-03	7.8335-03	1.3625-04	1.4231-03	5.2536-01
-3.5458+00	0.0000	6.6479+03	4.4464+05	7.3855-03	4.0729+00	1.1834+06	3.6246-05	1.1874-02	-1.0816+00
5.7779-03	8.1059-04	-7.9689+06	1.8849-02	1.4000+03	4.1953+00	7.5290+03	2.4505-05	6.5462-02	
20.0	1.7228+00	3.7767+02	7.2710-02	2.1172-06	3.0026-03	6.7214-03	1.3784-04	1.4345-03	5.2536-01
-3.5449+00	0.0000	6.6479+03	4.4464+05	7.3855-03	4.0361+00	1.1010+06	3.6961-05	1.2241-02	-1.0813+00
6.7100-03	9.3213-04	-7.9689+06	1.8849-02	1.4000+03	4.3081+00	8.6012+03	2.8458-05	6.5463-02	

THRUST LOSS = -2.0205680+02

REFERENCES

1. Frey, H. M. and Nickerson, G. R., Two Dimensional Kinetic Nozzle Analysis Reference Computer Program, Dynamic Science document no. CS-12-70-1, December, 1970.

2. Weingold, H. D., and Zupnik, T. F., Turbulent Boundary Layer Nozzle Analysis Computer Program-TBL, Prepared for the ICRPG Performance Standardization Working Group, July 1969, AD 841202.

APPENDIX A

ADDITIONAL PROGRAM FEATURES

This section describes several features of the Mass Addition Boundary Layer Program not discussed elsewhere in this report.

RESTART CAPABILITY

The Mass Addition Boundary Layer Program contains a restart capability which can save a significant amount of computer time when rerunning cases with altered wall and edge tables, different stepsizes or convergence criteria, etc. If the case in question yields satisfactory results up to a certain XLIM-station, the case may be restarted from that station with the appropriate changes to the input data. Implementation of the restart capability is described below. Note, however, that this feature has not been adequately checked out for all types of cases; therefore, results of a restarted case should be analyzed carefully.

Writing a Restart Tape

Logical unit 16 in the Mass Addition Boundary Layer Program is the unit which will contain the restart data and must be assigned to a save tape for a restart case. Saving of the necessary data at each XLIM-station is initiated by including the following variable in the DATA namelist:

IRSWR	Flag (integer) =0 (nominal) if no restart data is to be saved; =1 if restart data is to be written on logical unit 16 at each $\overline{x}/x_N$ value in the input array XLIM.

Restarting a Case From a Previously Saved Tape

To restart a case using previously saved data, all data from the original case must be reinput, with the following necessary changes in the DATA namelist:

IRSWR	Should be set to zero if the restart data used to restart this case is to be preserved; otherwise, if IRSWR=1, restart data at every XLIM-value encountered in this case will be written on the tape over the previous data.

IRSRD	= the value of the station counter at the initial station for this restart case. This value is used to locate the appropriate XLIM-station on the restart tape.
XINIT	Initial value of $\bar{x}/x_N$ for this case, the same as the value in the array XLIM corresponding to station IRSRD above.
SINIT	Initial value of $\bar{s}/x_N$ for this case.
DXI	Initial stepsize $\Delta\bar{x}/L$ for this case, the same as the value in the array DXLIM corresponding to station IRSRD above.
SKTAB XTABSK LSKTAB	Must be changes such that XTABSK(1) is greater than XINIT above.
DXLIM XLIM LDXIM	Must be changed such that XLIM(1) is greater than XINIT above.

If station IRSRD is not present on the restart tape, the following message is printed:

THERE IS NO RESTART DATA FOR STATION [IRSRD].

If the restart case is set up to duplicate the results of the original case for the first ten stations or so, the summary table printouts for these stations may be compared for possible discrepancies. Small errors in the restart case should, in general, damp out.

DIFFERENCE EQUATION DEBUG CAPABILITY

The ability to dump the difference equation coefficients and the current values of the dependent variables u, H, h, and ρv has been provided (See SUBROUTINE DUMPIT for further details.) and is implemented by entering values for the array IDEBUG in the DATA namelist as follows:

IDEBUG(1)	Flag (integer) =1 if the momentum equation coefficients are to be printed; =2 if the energy equation coefficients are to be printed.

IDEBUG(2)	Integer specifying the first station for which the coefficients and variables are to be printed.
IDEBUG(3)	Integer specifying the last station for which the coefficients and variables are to be printed.

Coefficients and values for the first five and the last five mesh points are printed for every iteration over the range of stations specified by IDEBUG(2) and IDEBUG(3).

VARIABLE LEWIS NUMBERS

The Lewis number Le and the turbulent Lewis number Le_T at each mesh point are currently set equal to ALEWIS and TLEWIS, where the latter are program constants set to unity in the main program TFCBL. However, back, average and forward values of Le and Le_T for each mesh point are stored in the program arrays BLE and BLET, so that a method of calculating variable Lewis numbers could be provided without difficulty. If this were done, the following areas of the current code would have to be changed accordingly:

(1) DØ 40 loop in main program TFCBL, which sets Le=ALEWIS across the boundary layer.

(2) DØ 600 loop in subroutine EDDY, which sets Le_T=TLEWIS across the boundary layer.

(3) DØ 4300 loop in subroutine HØØDE, which sets Le=1 across the boundary layer for an equilibrium case.

(4) The DØ 4910 loop at the end of subroutine HØØDE, which is currently bypassed, must be executed for $Le \neq 1$; the c_i's and h_i's must be obtained by interpolation for mesh points intermediate to the equilibrium calculations, since the terms containing them in the difference equations are now nonzero.

APPENDIX B

ADDITIONAL NOTES ON INPUT

REFERENCE QUANTITIES

The reference quantities are used to nondimensionalize the dependent and independent variables. By using reference values as close as possible to the values of each variable encountered in the solution, the normalized variables become more uniform in magnitude (all of order unity in an ideal case) and the possibility of round-off error is reduced. As long as significant round-off error is not encountered the calculated results are independent of the choice of reference values.

PROBLEM LIMITS AND INITIAL VALUES

DXI - It is desirable to start the solution with a series of small steps in order to damp out the initial truncation error inherent in starting from initial profiles that do not satisfy the differential equations. It appears that 30, or so, steps of the order of 10^{-5} to 10^{-4} feet is usually sufficient. The acutal number of small initial steps or their size can be varied over a considerable range without significantly affecting the results. DXI itself is the value of the initial step size. These initial steps can all be the same size or the step size can be slowly increased in a geometric progression. The controls for changing the step size are discussed later on.

DELTAI - See discussion of PLAW in constants section.

ZETAPI - The initial value of ξ' is normally not known and therefore the program has been designed to calculate one. The results are not sensitive to the value of ZETAPI as long as the solution is begun with a series of small steps.

CONSTANTS

PLAW (and DELTAI) - If one is starting from known initial conditions (experimental or theoretical) DELTAI is known and the known initial profiles can be input using the UPROF and HPROF arrays. In this case, PLAW is not needed. Normally, if initial conditions are not known, the solution should be started as close as is practicable to the origin of the boundary layer flow in order to reduce the overall effect of initial profile errors. If the boundary layer is started near its origin (DELTAI $\approx 10^{-4}$ or 10^{-5} depending on Reynolds number) then the effect of initial profile errors is quickly damped out as the boundary layer grows. Under such conditions the choice of PLAW is not important.

If, for some reason, a calculation must be started at a location where the boundary layer has appreciable thickness and the thickness and boundary layer profiles are not known, then the choice of DELTAI and PLAW can have a significant effect on the calculated results. Under such conditions one can do nothing more than use best estimates for DELTAI and PLAW.

GPO, SN3 - In most of the calculations performed to date, values of GPO of about 1000 and Sn3 = 4 have been used successfully. If very high Reynolds numbers are encountered larger values of GPO may be needed. GPO and SN3 have not been systematically varied to date so that a more detailed set of recommendations cannot be made at this time.

CONVERGENCE AND EDGE CRITERIA

EPSLN1, EPSLN2, EPSLN3 - It is suggested that values of the ϵ's in the range 10^{-1} to 10^{-2} be used. The solution is not sensitive to the values of the ϵ's. Normally when the solution terminates for adding too many points either the problem has been poorly posed (e.g. an input error) or the step sizes require modification. On rare occasions the program adds points extraneously due to a local numerical problem. If this should happen, increasing the value of ϵ can usually circumvent the problem.

COUNTERS

MAXIT - In the majority of cases MAXIT should be set equal to 1. Occasionally the oscillations in τ_w and q_w do not damp out (or amplify) with MAXIT = 1. If that is the case increasing MAXIT to 2 usually solves the problem.

NYI - The initial number of mesh points in the Y direction for turbulent boundary layer flows has been varied from 80 → 160 in the solutions obtained to date. Most of the computations have been carried out with NYI = 120. The exact number of mesh points to use is not critical since the computed results are usually fairly insensitive to the mesh spacing over a considerable range. The few laminar solutions which have been obtained used 60 or less mesh points (usually with no stretching - GPO and SN3 not input).

IYEQ - For H_2-O_2 equilibrium solutions a large part of the computer time is used in solving for the equilibrium concentrations of the species. To reduce the amount of computer time required to solve equilibrium H_2-O_2 boundary layer flows the species concentrations are solved for only at every IYEQth mesh point and the values at other mesh points are found by interpolation. For laminar flow solutions appreciable error can be encountered if IYEQ is much larger than 4. Based on current experience it appears that turbulent flows can be computed with IYEQ = 8 without introducing more than 1% errors.

STEP SIZE CONTROL TABLES

The XLIM, DXLIM arrays are used to effect discontinuous changes in step size. Sudden large changes in step size do not usually cause problems as long as they are not encountered too frequently. (Equilibrium solutions can be more sensitive to step size changes). A large step size change can cause a local perturbation in the solution which normally quickly damps out. If the step size is repeatedly changed by a significant factor, before the perturbations from the previous changes have disappeared, then erroneous results can be computed.

The SKTAB, XTABSK arrays allow continuous step size changes to be made. The step sizes form a geometric progression of common ratio SKTAB(K). If SKTAB is specified as one over a given X range, the step size will remain constant. SKTAB's less than one cause step size reductions and SKTAB's greater than one increase the step size. If the last value of X computed is denoted X_o, the latest step size is ΔX_o and SKTAB = K the following formulas can be used to compute the step size and distance covered after n additional steps

$$\Delta X_n = \Delta X_o K^n$$

$$X_n = X_o + \Delta X_o \frac{K^n - 1}{K - 1}$$

The two methods of varying the step size can be used separately or together to suit the requirements of a particular problem. A large number of problems have not yet been solved with the present program so only general guidelines, rather than exact step-size recipes, can be currently suggested. The size of the X steps to be used should be governed by the size of the gradients in X direction, e.g., dr_w/dx, dT_w/dx, dP_e/dx, $d\dot{m}/dx$, etc. The higher the gradients the smaller the step size required to maintain a given level of truncation error. Many times discontinuities in

one or several of the boundary conditions are encountered. Disco..tinuities should be handled essentially as if the solution were being started with approximate initial profiles. An XLIM value should be set equal to the value of X at which the discontinuity begins, the corresponding DXLIM entry should be used to reduce the step size to a small value (say $\approx 10^{-4}$ of the total length to be computed). This small step should then be maintained (or slowly increased by a K factor) for 30 or so steps until the perturbing effect of the discontinuity has been damped.

In regions where rapid gradients or discontinuities (including the initial "smoothing out" region) are not present, a step size on the order of 1/100 of the length to be computed has typically been used. Much smaller steps have been used without changing the results by more than 1 or 2%, however, the effect of larger steps has not been adequately determined. In regions with sizeable gradients smaller (than 1/100 the length) steps should be used. Experience will be the only guide as to how small a step one need take in order to achieve the desired accuracy.